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VACUUM SYSTEM FOR THE STANFORD-LBL STORAGE RING (PEP) *

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Summary

The vacuum system for PEP will be similar in design, construction and operation to the system currently in operation at SPEAR. There will, of course, be quantitative differences since the closed path of PEP will be 10 times longer than the SPEAR path. Some qualitative differences will also arise since the radiated synchrotron power for PEP will be about 13 times greater than for SPEAR giving rise to an increased linear power density incident on the chamber wall. Other differences arise from the higher energy spectrum of the synchrotron radiation.

The SPEAR vacuum system has been in operation since April 1972 and has proven satisfactory in design, construction and operation. The chamber has been subject to synchrotron radiation for approximately 300 ampere-hours and the beam lifetimes are now more than several hours.

The details of the PEP design and the SPEAR operating experience will be further discussed in this paper.

PEP

System Description

Ring Configuration. The PEP storage ring will be hexagonal in shape consisting of 6 arc regions and 6 straight insertion regions. The arc regions will be approximately 231 meters long and will consist of cells containing bend magnets and quadrupole magnets. The insertion region will be approximately 130 meters long of which 20 meters at the center will be reserved for beam interaction experiments. The balance of the insertion region will be occupied by beam injection and steering equipment, RF cavities, beam monitoring equipment, etc.

Vacuum Chambers. The PEP vacuum chamber will be constructed of aluminum extrusions and stainless steel tubing and will have a perimeter of 2100 m. The system will be designed to operate at an average pressure of less than 5×10^{-8} torr in the presence of 2.6 MW of synchrotron radiation in each beam. The interaction regions are being designed for an initial pressure of 5×10^{-9} torr with provision for adding pumps to bring the pressure down to 5×10^{-10} torr. The system parameters are listed on Table I.

The vacuum chambers inside the bend magnets will be 186 mm wide by 54 mm high 6061 alloy aluminum extrusions. The cross section of the chamber located in the bend magnets is shown on Fig. 1. The inner dimensions of the chamber are set by the requirements of the beam stay clear zone as determined by beam dynamics. The cooling water passage and internal distributed sputter ion pumps are shown on the figure. Each of these chambers will be continuous through two bend magnets. The chambers which pass through the quadrupole magnets will be aluminum extrusions of a different cross section. Flanges for the aluminum chambers are welded to an aluminum to stainless steel transition as described below.

Ion pumps, synchrotron radiation masks, bellows, valves, beam position monitors, pressure gauges, etc. are mounted on stainless steel tubes located between the bend magnets and quadrupole magnets. Initially the vacuum chambers in each insertion will consist of 10 m long sections of 203 mm diameter stainless steel tubing.

Table I

Vacuum System Parameters

	SPEAR	PEP
Vacuum Chamber Length		
Aluminum Extrusions		
Bend Chambers		
Single, m	8.99	11.90
Total, m	152.77	1142.40
Quadrupole Chambers		
Single, m	------	1.71
Total, m	------	164.16
Stainless Steel Tubing		
Modules*		
Single, m	2.64	.81
Total, m	20.13	77.76
Insertions		
Single, m	22.40	130.42
Total, m	44.81	782.52
Total Closed Path, m	217.71	2166.84
Cross Sectional Area		
Bend Chambers, cm^2	68.17	68.60
Quadrupole Chambers, cm^2	------	59.50
Modules, cm^2	324.29	324.29
Insertions, cm^2	324.29	324.29
Vacuum Chamber Volume,** ℓ	31.5×10^3	367.1×10^3
Holding Pumps Speed, ℓ/s	400	100
Number of Holding Pumps	32	216
Distributed Ion Pumps		
Total Speed, ℓ/s	16×10^3	230×10^3
Number of Inline Valves	6	30
Number of Bellows	52	312
Beam Energy, GeV	3.8	15.0
Beam Current (two beams), mA	200	200
Critical Energy, keV	9.6	44.1
Radiated Synchrotron Power	291 kW	5.2 MW
Average Linear Intensity		
Chamber Wall, W/cm	33	46
Mask, W/cm	53	213
Maximum Incident Power Flux		
Chamber Wall, kW/cm^2	1.10	1.59
Mask, kW/cm^2	.73	6.45
Maximum Cooling Water Heat Flux		
Chamber Wall, W/cm^2	26	23
Mask, W/cm^2	24	53
Maximum Local Temperature		
Chamber Wall, ^oC	111	111
Mask, ^oC	187	338
Base Pressure (no beams), torr	8×10^{-10}	1×10^{-9}
Operating Pressure, torr	2×10^{-8}	5×10^{-8}
Water Flow, ℓ/s	16.8	220

* Includes pump ports, beam monitors, etc.
** Excluding RF cavities

Vacuum System Features

Distributed Sputter Ion Pumps. The distributed sputter ion pumps will be similar to those used on SPEAR which were described in Ref. 1. The pump consists of an array of tubular cells in which gas molecules are ionized by the action of spiraling electrons. An applied potential of 7.3 keV accelerates the ions onto the titanium plates where sputtering ensues. The pumps are mounted inside the vacuum chamber between the pole faces of the storage ring bending magnets. The field of these magnets constrain the electrons to their spiral path within the pump cells.

The pump anode consists of cells which are 12.5 mm in diameter by 28 mm high and are made of 0.4 mm thick, type 304 stainless steel tubing. The PEP pumps will contain a single row of cells instead of the double row used on SPEAR. The cells are spot welded together to form a linear array. The entire anode assembly is supported on the pump cathode. The cathode consists of upper and lower 2.3 mm thick 99.8% pure titanium plates. The perforated aluminum screen serves as a sputter shield to protect the chamber from titanium deposits as well as a ground screen

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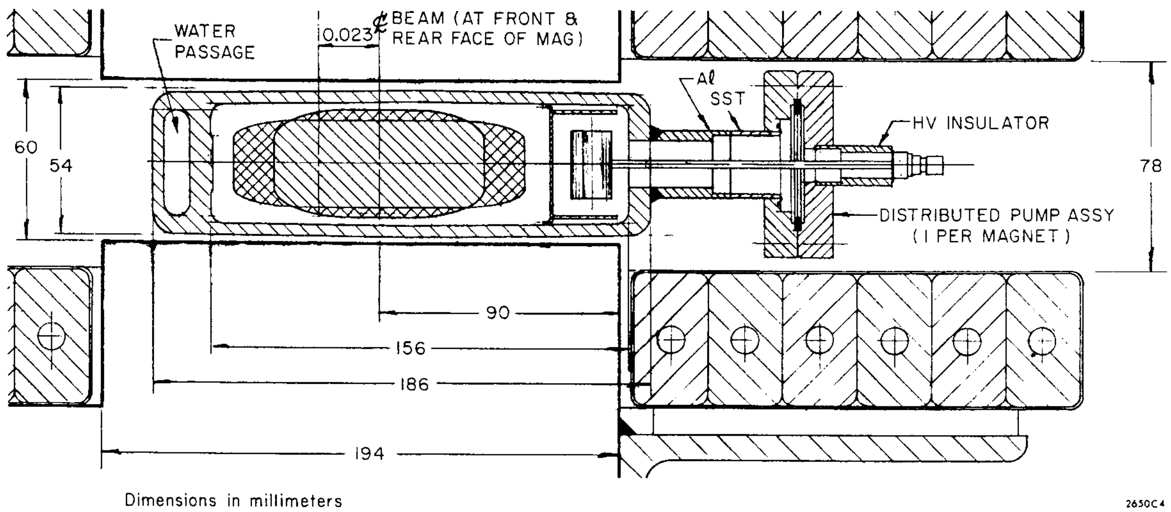

FIG. 1--PEP vacuum chamber.

to avoid perturbation of the electron-positron beams due to the pump potential.

The pumping speed is 200 ℓ/s per meter as shown in Ref. 1 and is essentially constant for fields higher than 3.5 kG. The SPEAR pumps have been in operation for over 15,000 hours and show no indications of saturation, degradation effects or other failure.

Details of Construction. There will be three 152 mm aperture straight through vacuum valves installed in each arc region. The valves will be able to be closed locally or remotely and will close automatically upon high system pressure. In addition there will be fast closing valves located at each of the insertion regions as well as individual isolation valves at the ends of the interaction regions and at each piece of major equipment in the insertion regions.

There will be stainless steel welded nested bellows installed on each of the modular sections at the quadrupole magnets. These bellows are provided to accommodate the thermal expansion of the extruded sections as well as for the purpose of permitting minor adjustment of the vacuum chamber position relative to other equipment.

The extruded chambers will be constrained from circumferential movement between each of the bend magnets. The ends of these chambers will be free to move circumferentially but will be constrained in the radial and vertical directions.

Design Considerations

Synchrotron Radiation. Internal surfaces which are subject to synchrotron radiation require cooling. The power which must be dissipated by such surfaces is intense and represents one of the major factors determining the vacuum system design. Conservative design criteria are necessary to minimize the danger of a water to vacuum leak. In addition, the synchrotron induced gas desorption gives rise to high gas loads.

At 15 GeV and 100 mA current in each beam, the total power radiated per beam will be 2.6 MW. Due to the vacuum chamber geometry, the maximum linear heat flux for electron-positron operation of the ring will be about 46 W/cm. The synchrotron radiation spectrum will extend to photons with energies well above 80 keV. The calculated maximum temperature on the vacuum side of the water cooled wall will be about 111^{o}C.

The critical energy for PEP at a beam energy of 15 GeV will be 44.1 keV which is about the energy at which Compton scattering of gamma radiation begins to dominate the attenuation coefficient in aluminum. It is estimated that 15% to 30% of the radiated synchrotron power will be scattered outside of the vacuum chamber walls.

System Pressure. The pressure rise due to synchrotron radiation induced gas desorption at SPEAR was approximately 0.2 nanotorr/mA at 1.5 GeV by the third month of operation. With a pumping speed of 16,000 ℓ/s this implies a throughput of 3.2×10^{-6} torr-ℓ/mA s. With a system pumping speed of 230×10^{3} ℓ/s, the average system pressure for PEP will be about 5×10^{-8} torr.

Bakeout. After assembly each chamber will be pumped and oven-baked prior to installation. There will be provision for baking the arc and insertion regions after installation. Present plans call for a 180^{o}C bake by circulating hot water under pressure through the cooling water passage of the aluminum extrusions.

SPEAR

System Description

Vacuum Chambers. The SPEAR vacuum system is approximately 218 meters in circumference and consists of alternate aluminum extrusion bend sections and stainless steel tubing straight sections. The vacuum chambers within the bend magnets have about the same cross section as those proposed for PEP. The straight sections have a diameter of 203 mm and contain the beam injection and monitoring equipment, RF cavities, holding pumps, etc. The system parameters are shown on Table I.

The design and construction details such as the use of stainless steel to aluminum transitions, distributed sputter ion pumps, bellows, etc. are very similar to those described above for PEP.

Fabrication and Installation

Extrusions. The extrusions were fabricated of 6061 alloy aluminum on a direct extrusion press using a porthole die. Extrusions were quenched at the press to yield T-4 properties. Die design and extrusion parameters such as billet temperature and extrusion rate were carefully controlled so as to produce extrusions with ultra high vacuum integrity. Extensive tests were made to verify the vacuum integrity of each extrusion.

Aluminum to Stainless Steel Transitions. All flanges larger than 102 mm in diameter are stainless steel UHV flanges with copper gaskets. Commercially available aluminum to stainless steel transition pieces were used to join these flanges to the aluminum chambers. Stock for these transitions, purchased under the trade name of "Detaclad" consisted of 50 mm layers of stainless steel and aluminum with a 0.8 mm thick interlayer of silver which were explosively bonded. Each piece was ultrasonically tested for the bonding integrity by the manufacturer. Additional vacuum and tensile testing was performed on representative samples from each piece of stock. This transition material was also used in other vacuum system components such as the synchrotron radiation masks discussed below and shown on Fig. 4.

Installation. Each chamber was assembled in a clean area, leak checked and baked for four days to over 150°C. The chambers were maintained under vacuum until ready for installation in the ring. During and after installation the chambers were continuously pumped or vented to dry nitrogen at all times. Except for the case discussed below, there was no subsequent bake of the vacuum chambers.

Operating Experience

System Pressure. There are approximately 14 vacuum gauges located in the various straight sections of the ring and the pressure indication varies somewhat from location to location. Initially the ring pumped down to the low 10^{-9} torr range and is currently in the mid 10^{-10} torr range.

Synchrotron radiation induced gas desorption is a function of the radiation spectrum and the condition and history of the irradiated surface. The measure of this gas desorption is the pressure rise when beams are stored in the ring. Continuous exposure to synchrotron radiation "conditions" the surfaces and the pressure rise decreases. The pressure rise which was initially 10 nanotorr/mA with a beam energy of 1.5 GeV decreased to 1 nanotorr/mA after 1 month of operation, 0.2 nanotorr/mA after 2 months and is now between .01 and .03 nanotorr/mA.

Measurements of pressure rise as a function of beam energy are shown on Fig. 2. The pressure rise at 1.5 GeV decreases from 0.06 nanotorr/mA in January 1973 to a low value of 0.01 nanotorr/mA in June 1974. The value of 0.03 nanotorr/mA in February 1975 is probably due to the fact that this measurement was made early in the run and the system was still recovering from exposures to atmospheric pressure nitrogen. There is a definite indication that the slope of the pressure rise as a function of beam energy decreases as the ring is "conditioned" at higher energies.

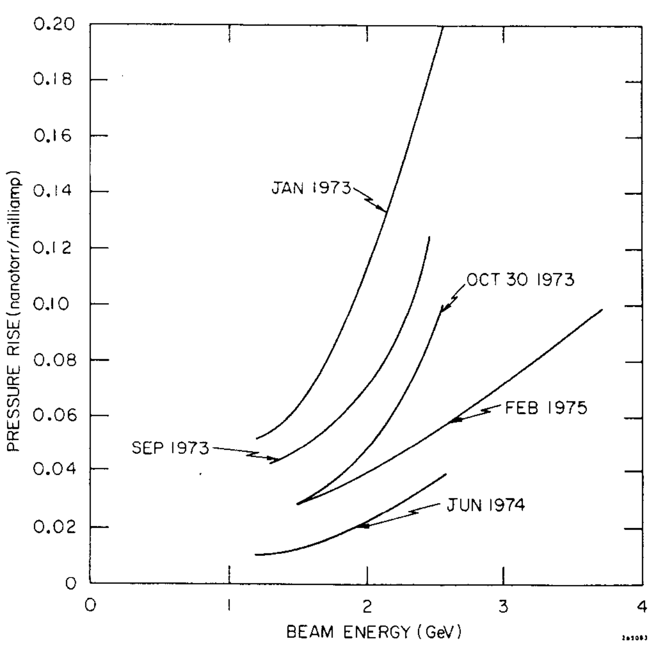

FIG. 2--SPEAR pressure rise.

A typical gas composition scan is shown on Fig. 3. This scan was taken with a quadrupole mass analyzer during a run in January 1973. The beam current was 40 mA at an energy of 2.12 GeV. The total pressure was 9×10^{-9} torr and the gas composition shown is:

Hydrogen	60%	Water Vapor	4%
Carbon Dioxide	25	Methane	3
Carbon Monoxide	6		

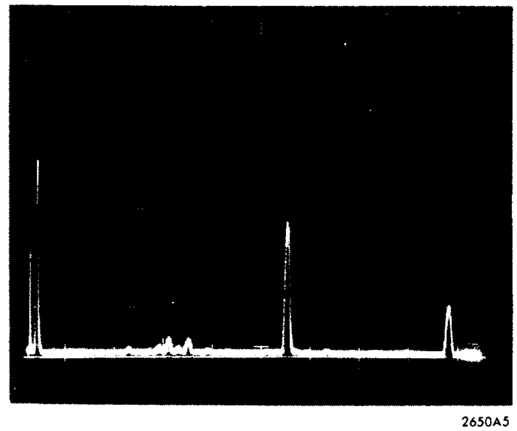

FIG. 3--SPEAR residual gas scan.

Synchrotron Radiation and Masking. Radiated synchrotron power incident on the aluminum vacuum chamber is absorbed by the water cooled wall of the chamber. Aluminum masks were provided in the straight sections to shield the stainless steel walls as well as equipment within the chamber such as beam position monitors, bellows, etc. Inspection of the masks after twelve months of operation disclosed some surface marking in the zone subject to the synchrotron radiation. The marking which is seen on the vacuum face of the mask shown on Fig. 4 became clearly visible only after the mask was given a light etch. Metallagraphic examination of these sections of material could detect no evidence of damage below the surface.

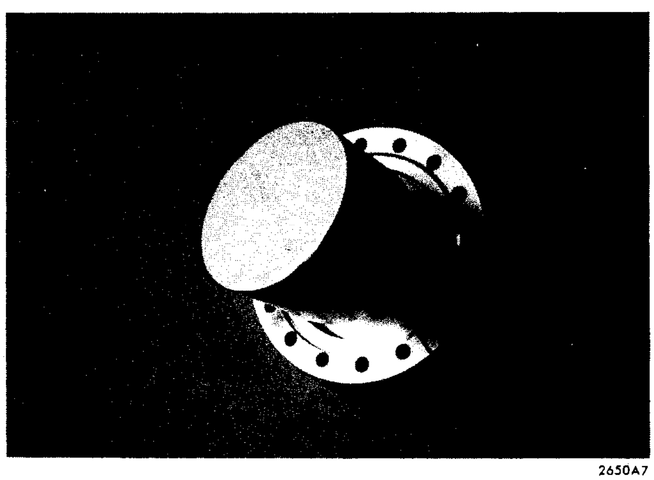

FIG. 4--SPEAR synchrotron radiation mask.

Bakeout in Place. Bakeout after installation has been required on only one occasion. In January 1974 the south arc of the ring developed a leak due to failure of a ceramic to stainless steel braze on a high frequency cavity. After replacing the chamber, the pressure could not be brought below 10^{-7} torr despite attempts at "beam conditioning." The chamber was baked for four days at 140°C with continuous nitrogen gas purge followed by three more days of baking and pumping. This treatment restored the base pressure to the normal low 10^{-9} torr range.

Reference

1. U. Cummings et al., "Vacuum System for Stanford Storage Ring, SPEAR," J. Vac. Sci. Technol. 8, 348 (1971).