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THE POSITRON-ELECTRON PROJECT—PEP*

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Summary

PEP, an 18-GeV electron-positron colliding-beam storage ring facility at SLAC, is being built by a team from LBL and SLAC. Construction is under way and completion is scheduled for Fall of 1979. This report summarizes the design of the facility and reports on the status of the project.

Introduction

The positron-electron project PEP, a joint venture of the Lawrence Berkeley Laboratory and the Stanford Linear Accelerator Center, has entered the construction phase. It is located on the SLAC site because of the availability there of the two-mile linear accelerator. Engineering design began in April of 1976, which marks the formal beginning of the project, and actual construction began in October of 1976 with the erection of some specialized component-production buildings and the initiation of procurement. The Architect-Engineer-Manager joint venture of Parsons, Brinkerhoff, Quade and Douglas, Inc., and Kaiser Engineers started work under contract in December, 1976.

The history of the project, which dates back to the original feasibility study of a positron-electron-proton colliding-beam system,[1] is traced in earlier publications.[2,3] Completion of construction is expected some time between September, 1979, and April, 1980, depending mainly on fiscal constraints. The total cost is estimated to be $78 million. The project is supported by the U. S. Energy Research and Development Administration.

The main component of the PEP facility is a storage ring in which beams of positrons and electrons circulate in opposite directions in a vacuum chamber embedded in a magnetic guide field having six bending arcs and six long straight sections. The major diameter of the ring is about 710 m and the radius of the arcs is about 240 m. The facility is shown in Fig. 1. The electrons and positrons to be stored in it are produced in the SLAC linac and are introduced into the storage ring via two beam transport paths emanating underground from the end of the two-mile accelerator. One path joins the storage ring in the northwest straight section and the other in the southwest straight section. Beams of energies up to 18 GeV can be stored, and, at a future date, components could be added to permit energies above 20 GeV.

The energy lost from the beams by synchrotron radiation is restored by a high-power radiofrequency accelerating system which employs klystrons to drive the accelerating structure at a frequency of 353 MHz. The system delivers several megawatts of power to the beams and since much of this power appears as synchrotron radiation which strikes the outer wall of the vacuum chamber, that wall must be water-cooled. Moreover, the radiation initiates the well-known desorption process and the desorbed gases must be pumped away very rapidly because low pressures (about 10^{-8} Torr) must be maintained in the vacuum chamber to achieve adequate beam lifetimes of several hours. These low pressures will be sustained by means of long, narrow sputter-ion pumps located in the vacuum chamber in the bending magnets directly alongside the beams.

The storage ring is designed to generate a luminosity as depicted in Fig. 2 and to operate over the energy range 4 GeV to 18 GeV. To achieve this performance with the PEP design it is necessary to store a particle current of up to 55 milliamperes in each beam. Based on the performance of the SLAC two-mile accelerator in filling SPEAR II, the filling time for PEP will be a few minutes, which is a comfortably short period compared to the storage time of several hours and ensures that storage ring operations will consume only a small fraction of the linear accelerator beam time.

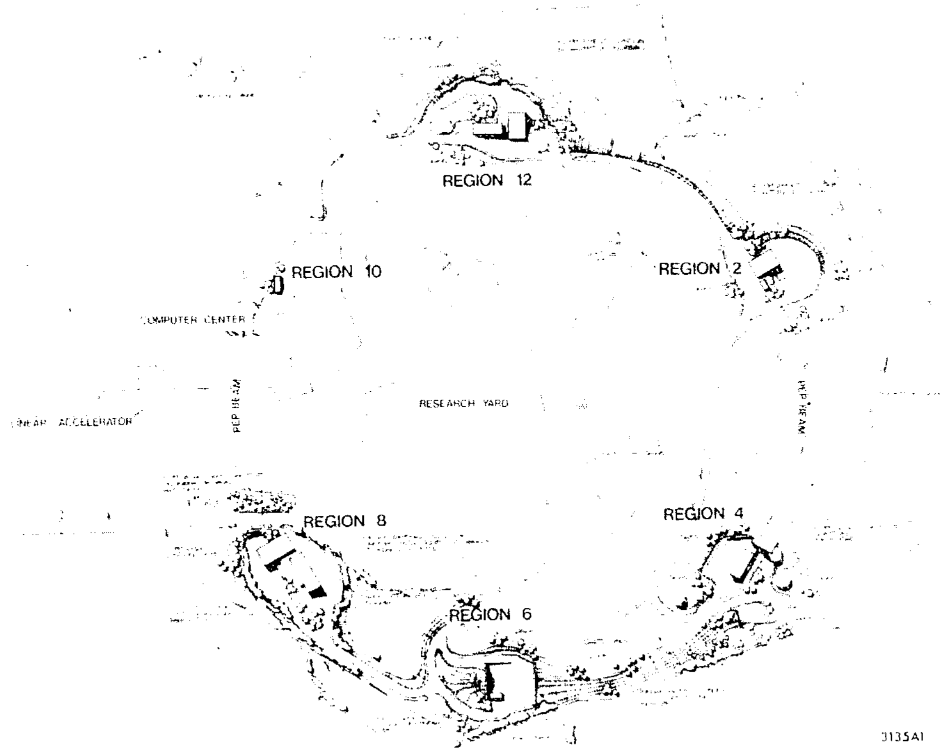

Fig. 1. Layout of the PEP facility on the site.

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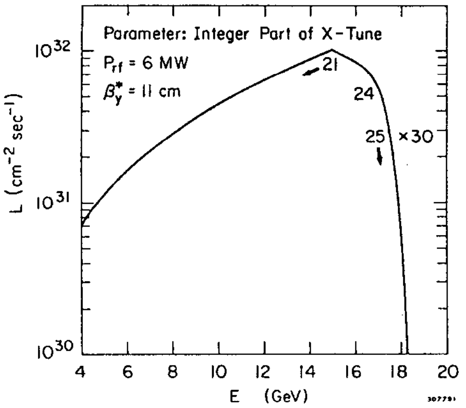

Fig. 2. Design luminosity as a function of beam energy.

Each counterrotating beam will be concentrated into three bunches, each a few centimeters long and equally spaced around the ring, with the result that the bunches will collide only at the centers of the six interaction regions. Five of these interaction regions will be housed in experimental halls of various designs where high-energy-physics experiments will be carried out. The sixth interaction region (northwest) will be reserved primarily for accelerator physics measurements although it will be compatible with particle physics experiments on a modest scale.

The main parameters of the PEP storage ring are summarized in Table 1.

Table 1

Main Storage Ring Parameters

Nominal maximum energy	18	GeV
Minimum operating energy	4	GeV
Maximum current per beam (at 15 GeV)	55	mA
Number of particles per beam (at 15 GeV)	2.5×10^{12}	
Design luminosity per interaction region		
Maximum luminosity at 15 GeV	1×10^{32}	cm^{-2}sec^{-1}
Below 15 GeV	$10^{32}(E/15)^2$	cm^{-2}sec^{-1}
At 18 GeV	1.5×10^{31}	cm^{-2}sec^{-1}
Number of interaction regions	6	
Available free length for experimental setup	≈ 19.0	m
Circumference	2200.00	m
Symmetry	sixfold	
Average radius	350.14	m
Largest diameter	710.84	m
Smallest diameter	677.76	m
Average radius with normal periodic cells	219.92	m
Magnetic radius	165.52	m
Bending magnet filling factor in cells	75	%
Length of interaction straight section	117.09	m
Length of bend section	243.92	m
Length of symmetry straight section	5.66	m
Orbital frequency	136.27	kHz

Beam Dynamics[6]

Lattice

To attain high luminosity, intense beams must be made to collide within a small cross-sectional area. The number of particles which can be collided within a given area is limited by the incoherent beam-beam interaction. When beam currents are limited by the beam-beam interaction, the maximum theoretical luminosity, $\mathscr{L}_{max}$, is attained when the transverse beam size is made as large as the vacuum chamber permits. If one operates a storage ring at different energies with exactly the same disposition of magnets and with their fields scaled with energy, the transverse be beam dimensions vary directly as energy and the maximum (beam-beam-interaction-limited) number of stored particles varies as E^3; thus the luminosity varies as E^4 and drops off very rapidly at lower energies. If, however, by some technique, the beam size is held constant as the energy is lowered, then the maximum number of stored particles varies as E and the luminosity as E^2. This E^2 dependence is quite acceptable; most reaction cross sections increase at lower energies.

The PEP design provides several different methods for horizontal beam-size control. They include: (1) variation of the betatron tune, (2) variation of the momentum dispersion function at the interaction point, (3) unmatching the momentum dispersion function so that it does not repeat periodically from cell to cell but oscillates with amplitudes large compared to its matched value, and (4) additional radiation excitation of betatron oscillations with the help of the "wiggler magnet system", which is explained in more detail later in this section. Vertical size can be adjusted by means of variable horizontal-vertical betatron-oscillation coupling. Using these techniques or combinations thereof, it should be possible to approach closely the design luminosity shown in Fig. 2.

In order to implement techniques (1), (2) and (3), the values of β_x^*, β_y^*, η^* and the radial tune ν_x are independently adjustable.† In addition, the vertical tune ν_y is adjustable in order to maintain stable beam confinement. Symmetry of the ring requires that the slopes of the betatron and dispersion functions vanish at the interaction region; i.e., $\beta_x'^* = \beta_y'^* = \eta'^* = 0$. Thus, eight mathematical constraints are imposed on the focusing strengths, requiring at least eight sets of quadrupoles with independently variable strengths. A number of other important constraints must also be considered. There must be nineteen meters of drift space kept free for experiments at the interaction regions. The maximum values of the β-functions and η-function must everywhere be kept within reasonable bounds in order to minimize aperture requirements and to reduce chromaticity and other aberrations. Magnetic-field values must be kept within conservative limits. Furthermore, space must be reserved for various components such as RF cavities, injection components (septum magnets and kickers), vacuum equipment, rotated quadrupoles, sextupoles, beam monitors and control devices, electrostatic plates for separating the beams, and other miscellaneous instrumentation.

From the considerations mentioned above, we have evolved a lattice design which is basically rather simple. The six bending arcs are composed of conventional separated-function bending cells which provide independent control of the total betatron tunes ν_x and ν_y by means of the independently controllable focusing and defocusing quadrupoles. Spaces between the quadrupoles and bending magnets in these cells provide space for the sextupoles which are necessary to control chromaticity, beam monitors, vacuum bellows and other devices.

Two major changes in the lattice design have been made since PEP was last described in the open literature.[3] (1) At the symmetry point, halfway between any two interaction points, a straight section of 5.66 m has been introduced. It is here that the separation in time between the passage of two bunches in either direction is the longest, making it easier to control each bunch individually. This place is, therefore especially suited for beam-control devices; e.g., feedback systems to control coherent beam oscillations and RF cavities to split the synchrotron frequencies. (2) The number of FODO cells has been doubled to 96 while the tunes and circumference of the storage ring have been kept approximately constant.[4] The second change has been accomplished by doubling the number of quadrupoles while keeping the strength of each about the same. The betatron phase-shift-per-cell is thus reduced to about 45° at 15 GeV, resulting in a "smoother" beam envelope. The maximum values for the betatron functions in the cells are thereby reduced relative to the values at the interaction regions, so that the beam size in the cells is reduced and with it the required apertures. Another attractive consequence is the possibility of extending

†The symbols used in the text are defined in the tables.

the maximum operating energy well beyond 15 GeV, as explained in Ref. 4. Although doubling the number of cells did not change the luminosity expectations for energies below 15 GeV, the 96-cell lattice will make it possible, by adding to the RF system, to go to energies well above 20 GeV with a luminosity which drops off only as $\mathscr{L} \sim E^{-3}$. To achieve this it is necessary to continue the variable-tune capabilities to energies above 15 GeV.

The short 5.66-m straight sections at the middle of the arcs impose new matching requirements. Two additional sets of independently variable quadrupoles are adjusted to match the β_x and β_y functions to accomplish this. The dispersion function is then only slightly mismatched, and there seems to be insufficient reason for varying an additional quadrupole to obtain an exact match.

Control of Beam Size with the Beam Wiggler

Of the methods of beam-size control enumerated above, the first three impose severe penalties in filling rate at low energies, because they all result in momentum acceptances which decrease with decreasing energy. This would lead to rather long injection times below 10 GeV, since the damping times vary as E^{-3}. To avoid this difficulty a system has been devised to control the beam size without changing the lattice configuration, the tune or the momentum acceptance.[5] In this scheme high-field wiggler magnets are used to increase the quantum excitation of the beam and concomitantly the damping rates with only a trivial effect on the focusing. As the strength of the wigglers is increased the excitation increases faster than the damping and the natural beam size increases.

The wiggler unit proposed for PEP consists of three rectangular flat-field bending magnets with equal field strength closely adjacent to one another. The two outboard magnets are half as long as the central magnet, so the net displacement and deflection of the orbit is null. The magnets are placed close together to minimize their optical effects. Three such triplets, located in three of the six symmetry straight sections, will be used to obtain the desired variation of beam size at all energies below 15 GeV.

The physical effect of increasing the strength of the wiggler system is to increase the mean energy of the synchrotron radiation photons. This in turn enhances the perturbing effect of the emission of a photon on the betatron oscillation of the emitting particle. Since the photon emission is random, the increase of the beam size is completely incoherent. The amount of blowup of the beam can be smoothly adjusted by adjusting the strength of the wiggler system. Calculations show that the effects on beam dynamics (tune, betatron and dispersion function) are negligible. Only the horizontal beam emittance is directly affected by the wigglers. The vertical beam emittance and hence the vertical beam size will be increased by coupling the horizontal and vertical betatron motions by means of coupling elements such as rotated quadrupoles.

No increase in the installed RF power is necessary to make up the losses due to the additional synchrotron radiation caused by the wiggler which is turned off at energies of 15 GeV and above. Below 15 GeV, where it is turned on, the RF demand decreases rapidly with energy and is always less than the total installed RF power. The local synchrotron radiation power produced by the wiggler, however, is larger than that produced anywhere else and requires some special absorbers in the vacuum system.

The lattice configuration used with the wiggler system at beam energies up to 15 GeV is called the Standard Configuration. Some of its properties are collected in Table 2.

Magnet System[7]

The linear guide field selected for PEP is a separated-function system in which, for the most part, rectangular, flat-field dipoles provide the bending field and quadrupoles provide the focusing field. A number of correction magnets,

Table 2

General Beam Parameters for the Standard Configuration at 15 GeV

Tunes (typical)	ν_x =	21.25	
	ν_y =	18.75	
Momentum compaction factor	α_c =	0.00298	
Natural beam emittance	σ_x^2/β_x =	1.38	10^{-7} rad m
Natural energy spread	σ_ε/E =	0.1	%
Uncorrected chromaticities	ξ_x =	- 41.7	
	ξ_y =	- 158.3	
Transverse damping times	$\tau_x = \tau_y$ =	8.1	msec
Energy variation of damping partition no.	$\partial J/[\partial p/p]$ =	291	
Betatron function			
at interaction point	β_x^* =	2.80	m
	β_y^* =	0.11	m
maximum values in insertion quadrupoles	$\hat{\beta}_x$ =	240	m
	$\hat{\beta}_y$ =	910	m
Eta function at interaction point	η^* =	- 0.49	m
Linear beam-beam tune shift	$\Delta\nu_x = \Delta\nu_y$ =	0.06	
Optimum coupling	K =	0.26	
Beam size at interaction point			
($\sigma_{x\beta}^*$ = 0.60 mm, $\sigma_{x\eta}^*$ = 0.49 mm)	$\sigma_{x\,tot}^*$ =	0.77	mm
	σ_y^* =	0.03	mm
Bunch length for very small beam current	σ_ℓ =	21	mm
Number of bunches per beam	N_b =	3	

such as sextupoles, rotated quadrupoles, wiggler magnets and low-field bending magnets, are interspersed among the main ring bending and quadrupole magnets to perform beam correction functions. Laminated construction was selected for the dipoles and quadrupoles, both to reduce capital costs and to insure uniformity magnet-to-magnet by shuffling laminations. The laminations are sandwiched between thick end-plates. Aluminum coils are used throughout.

The characteristics of the dipoles, the quadrupoles and the sextupoles are tabulated in Table 3. The low-field bending magnets are used at the ends of the arcs to reduce the

Table 3

Magnet System

Standard bending magnet					
bending radius			ρ =	165.5176	m
magnet length			ℓ_B =	5.40	m
gap height			H =	70	mm
pole width			W =	210	mm
total number			N_B =	192	
Low-field bending magnet					
bending radius			ρ =	2500.0	m
magnet length			ℓ_{BL} =	2.00	m
total number			N_{BL} =	24	
Wiggler magnets					
maximum field			B_{max} =	2.0	T
magnet length (central/lateral)			ℓ_w =	0.4/0.2	m
number of wiggler triplets			N_w =	3	
Standard quadrupoles					
maximum gradient			g =	16	T/m
bore diameter			2R =	120	mm
magnet length	ℓ_Q = 1.0	0.75		0.38	m
total number	N_Q = 24	204		12	
Insertion quadrupoles					
maximum gradient			g =	7.0	T/m
bore diameter			2R =	160	mm
magnet length		ℓ_Q = 2.0		1.5	m
total number		N_Q = 12		12	
Sextupoles					
maximum strength	$g' = (\partial^2 B_y/\partial x^2)$		g' =	600	T/m²
bore diameter			2R =	140	mm
magnet length			ℓ_s =	0.25	m
total number			N_s =	192	

critical energy of the synchrotron radiation emitted toward the interaction region and ameliorate experimental background problems.

Radiofrequency System[8]

The synchrotron radiation energy radiated by a 15-GeV electron circulating once around the PEP ring is 27 MeV. Additional energy is lost due to the excitation of parasitic modes in the RF structure itself, in vacuum chamber boxes and at vacuum chamber discontinuities around the circumference of the ring, and this energy loss is estimated to be 7 MeV at a circulating current of 55 mA, assuming the worst case of no bunch lengthening. In addition to restoring these losses, the RF accelerating cavities must provide an overvoltage in order to insure a useful quantum lifetime. At the PEP radiofrequency of 353 MHz a peak RF voltage of 49 MV is required for operation at 15 GeV with 55 mA stored in each beam. Characteristics of the system are collected in Table 4.

Table 4

Rf System Parameters at 15 GeV

Energy loss per turn	U_s =	27.06	MeV
Minimum peak rf voltage	V_{rf} =	49.0	MV
Rf frequency	ν_{rf} =	353.210	MHz
Harmonic number	k =	2592	
Synchrotron frequency	ν_s =	0.05	
Number of accelerating sections	N_{cy} =	24	
Number of ½-MW klystrons	N_{KL} =	12	
Total active length of cavities	ℓ_{cy} =	50.925	m
Total shunt impedance[1]	R_{tot} =	1070	MΩ
Rf power installed	P_{rf} =	6.0	MW
Synchrotron radiation power for both beams	P_{syn} =	3.0	MW
Higher-order-mode losses[2]	P_{HOM} =	0.8	MW
Fundamental-mode loss in cavities	P_{cy} =	2.2	MW

[1]The definition of shunt impedance used here is V_{rf}^2/P_{cy}.
[2]This figure is for natural bunch length.

For operation at 15 GeV and above, a total RF power of 6 MW is required. This power is to be supplied by 12 klystrons, each delivering a CW output power of 500 kW to a power splitter which in turn feeds two accelerating sections of which there are 24. Each section is 2.1 m in length and comprises five tightly coupled cavities operating in the π-mode and similar in design to the SPEAR II cavities. The system is distributed to three of the six long straight sections, viz. Regions 4, 8 and 12. (See Fig. 1.) The installation is compatible with future expansion in both the number of accelerating sections and the number of klystrons, making possible operation at beam energies above 20 GeV. Differential distortions of electron and positron equilibrium orbits due to the discrete distribution of the RF system are calculated to be tolerable.

Figure 3 is a photograph of the 500-kW CW, 353-MHz klystron which is presently in a very promising state of development at SLAC. Both this klystron and the overall system design are treated in more detail in Ref. 8.

Vacuum System

The design of the PEP vacuum system is based largely on materials and fabrication techniques used successfully in the SPEAR vacuum system.[9] The vacuum chambers in the arcs are made primarily of 14-m-long, 6061-T4 aluminum extrusions carrying a separate water passage to cool the outside wall where synchrotron radiation hits and providing space at the inside of the beam-stay-clear region for distributed ion pumps in the bending magnets. These chambers contain beam position monitors and synchrotron-radiation masking for the stainless steel bellows between chambers which provide for thermal expansion and contraction. The

Fig. 3. Photograph of a full-scale model of the PEP 500-kW CW, 353-MHz klystron.

flanges are stainless steel, and junctions between aluminum and stainless steel are effected by the use of explosively-bonded aluminum-stainless steel sandwich material which has given successful and highly reliable service in SPEAR.

Criteria for the pumping system and the water-cooling system in the arcs are based on conditions of operation which would prevail if 5 MW of synchrotron radiation were emitted at 15 GeV in order to provide for future expansion of the RF system to improve luminosity at high energies. The maximum linear heat flux through the water-cooled wall due to both beams is about 46 W/cm except in the vicinity of the wiggler magnets where it is somewhat higher. The gas load in the arcs, which during operation is dominated by synchrotron-radiation-induced desorption, has been estimated by extrapolation from SPEAR data to be 10^{-5} Torr ℓ/s/mA. To handle this load, 800-ℓ/s distributed pumps are mounted in each of the 192 bending magnets which, taken together with 108 100-ℓ/s, commercially-available holding pumps located in the arcs, provide in all about 164,000 ℓ/s of pumping speed, yielding an estimated average pressure in the arcs of about 2×10^{-8} Torr. All pumps are of the sputter-ion type.

In the long straight sections radiation desorption is negligible and the main gas load is due to thermal outgassing. In these sections 300-series stainless steel tubing will be used as the vacuum chamber and pumping will be accomplished by commercially-available ion pumps distributed in different ways in different straight sections so as to hold the average pressure to 5×10^{-9} Torr.

For bake-out two systems have been designed, one for the arcs using 185°C water at 18 atm and the other for the long straight sections using electrical heating tapes. An argon-discharge system for cleaning the interior surfaces of the vacuum system now under investigation shows great progress and may even supplant one or both of the bake-out systems.[11]

In view of the concern regarding the higher-order-mode losses evidenced at SPEAR,[10] changes and discontinuities in vacuum chamber cross section will be held to a minimum. The individual sections of vacuum chamber will be continuous through two bending magnets and two quadrupoles, and mesh screens will mask the beam from unavoidable abrupt changes in chamber cross section caused, for example, by bellows and pump ports.

A particularly thorny problem arises in PEP because of the hardness of the synchrotron radiation spectrum. Above the critical energy of 46 keV (at 15-GeV beam energy) Compton scattering begins to become the dominant process by which photons are removed from the swath of synchrotron radiation striking the outer chamber wall, with the result that about 28% of the radiated power is spewed out of the cooled wall. The radiation scattered out of the chamber altogether must be dealt with to avoid damage to magnet coils, production of corrosive chemicals in the air, etc. That which is scattered laterally across to the inside of the chamber deposits heat in the structure of the distributed pump which, if not conducted away adequately, will raise the structure's temperatures to levels which vitiate the pump's capacity.

Injection System

The injection system transports the electron and positron beams from the two-mile linear accelerator to the storage ring and switches them onto stable orbits within the vacuum chamber of the PEP ring. The SLAC beams have the following parameters:

Energies	4 to 15 GeV
Momentum width	±0.5%
Emittance, positrons	0.2 π (15 GeV/E) mm-mrad
Emittance, electrons	0.02 π (15 GeV/E) mm-mrad
Particles per pulse	1.3×10^8 positrons, and 1.3×10^9 electrons
Repetition rate	up to 360 pps

Injection takes place at the operating energy of the storage ring.

The transport system has been designed to transmit a momentum width of ±0.8% with a resolution of at least ±0.3%. The magnet apertures are determined largely by the momentum passband. The monoenergetic emittance of the SLAC linac is easily transmitted and is only of secondary importance in determining the required apertures in the transport system.

The injection process whereby electrons or positrons from the linac are trapped in the PEP storage ring has two steps: (1) a launch into a stable orbit in the ring, having large-amplitude betatron oscillations, followed by (2) a slow damping of that oscillation down into a small-amplitude equilibrium distribution.

The entering particles are deflected horizontally by a pulsed kicker onto an orbit in which they can safely circulate within the vacuum chamber with a radial collective betatron oscillation of 2- or 3-cm amplitude, depending on the lattice configuration in use. To compensate the effect of this kicker on the beam already stored in the ring, it is made part of a triad of pulsed magnets whose function is to distort, or bump, the local closed orbit at the time of injection.

The loading time of the storage ring is short but not negligible. To load 55 mA of electrons and positrons into the ring at 15 GeV from the linac operating at 360 pps takes about 5 minutes. This maximum repetition rate of 360 pps is possible only at energies greater than 12.5 GeV, because of the damping time in the storage ring which increases with decreasing energy. At lower energies, the damping times in the normal lattice would increase as E^{-3}. However, the wiggler system serves to shorten the damping times so that the effective energy dependence is approximately E^{-2}. The required current in the ring varies as E, so that the overall filling time below 12.5 GeV varies approximately as E^{-1}, as shown in Fig. 4.

Physical Plant

The terrain of the site varies in elevation by as much as 30 m. It is highest along the linear accelerator axis and slopes away to both the north and the south. (See Fig. 1.)

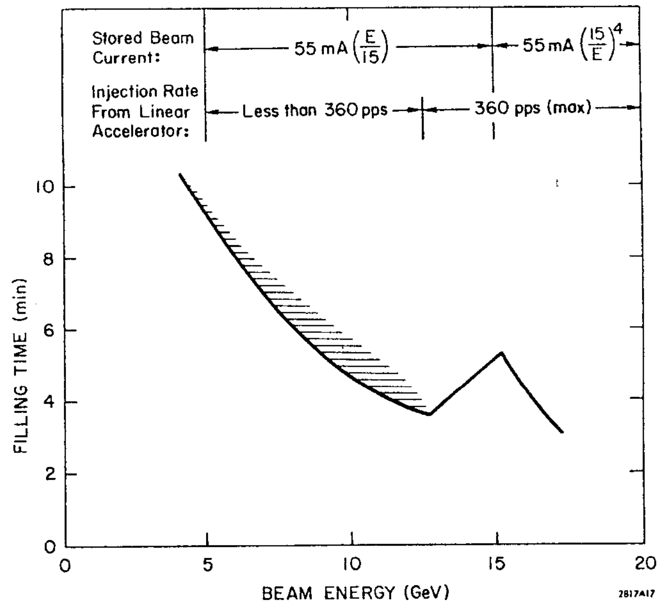

Fig. 4. Filling time into PEP assuming that only 25% of the current from the linac is ultimately trapped in the PEP ring.

Consequently, most of the interaction regions will lie in low areas. The centerline of the ring housing is to be at an elevation of about 66 m above mean sea level and will pass about 10 m below the floor of the SLAC beam switchyard. In the low terrain between Regions 4 and 8 and between Regions 12 and 2, the storage ring housing will be constructed by cut-and-cover methods; elsewhere it will be constructed by tunneling methods. The housing will have a minimum inside diameter of 3.35 m. The minimum earth-shield thickness over it will be 5.5 m which has been calculated to be adequate to shield the 200-GeV proton storage ring which may be added to the e^+-e^- ring some time in the future.[2]

Surface buildings to house instrumentation and control equipment, RF power equipment, toilet facilities, etc., will be located near the interaction areas. RF facilities will be located in Regions 4, 8 and 12, and instrumentation and control housings will be required at all interaction areas. Economical construction will be used but architecture and landscaping will confirm to the rural aspect of the site.

Experimental halls are located at Interaction Regions 2, 4, 8 and 12, and a 20-m-by-20-m open concrete pad is provided at Region 6. Figure 5 is an architectural sketch of the structures at Region 8. The surface building to the right

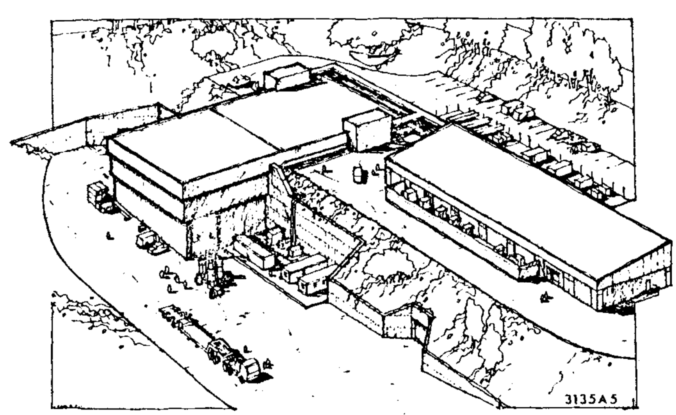

Fig. 5. Architectural sketch of the experimental hall and support building at Region 8.

houses the PEP control room, four of the twelve RF klystron stations which feed cavities in the tunnel below, magnet power supplies and instrumentation and control computers and other gear. The large, partially subterranean building to the left is the experimental hall; its internal dimensions are 11 m high, 41 m transverse to the beams and 20 m along the beams. The volume within the hall designated for the containment of experimental setups within the shielding enclosure (which is partially closed by movable shielding) is 10.5 m high to the crane hook, 20 m transverse and 20 m along the beam. The beam line is centered laterally within this volume and 4 m above the floor. The other halls provide somewhat smaller volumes for detectors but all have the same vertical clearances above and below the beam line.

The total installed ac power capacity for the storage ring and experimental equipment is 40 MW and the water-cooling capacity is 28 MW, expandable to 38 MW.

Status

The design of the physical plant is well started and the component-production buildings in the SLAC campus shop area, mentioned in the introduction above, are nearly complete. The first major excavation, which will be for the subterranean junction of the PEP injection-line tunnels with the existing linac housing, is scheduled to begin in May. Site preparation, preliminary excavation for experimental halls, construction of access roads and installation of utilities will begin in August, and the largest single work package which comprises the ring housing, the injection tunnels and the concrete shells of the experimental halls is scheduled to start in September.

Major procurements of magnets, RF cavity parts, vacuum system components, computers for monitoring and control, etc., are currently in progress. Models have been built and tested of the ring dipole magnets, the ring quadrupole magnets, the interaction-region quadrupoles, the RF accelerating section, the 500-kW klystron and many other components.

Progress to date gives good reason to hope for completion of the facility in Fall of 1979 as scheduled.

Acknowledgments

The work reported here is that of the whole joint LBL-SLAC project team; the author is only their spokesman. It is a pleasure, however, to recognize the special efforts of C. S. Nissen and H. Wiedemann in the preparation of this paper.

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   A. W. Chao and M. J. Lee, "Vertical Beam Size Due to Orbit and Alignment Errors."
7. Other papers related to the PEP magnet system presented to this conference are:
   R. Servranckx, "Magnetic Field Quality Requirements for PEP," and
   L. T. Jackson, "PEP Magnet Power Supply Systems."
8. Other papers related to the PEP RF system presented to this conference are:
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