PRESENT AND FUTURE DEVELOPMENTS ON THE SLAC THREE-KILOMETER ACCELERATOR*

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Introduction

This paper reviews the innovations which have recently been made or are being planned on the SLAC three-kilometer accelerator. Starting with a brief review of overall performance statistics, the paper follows the beam from its origin to the experimental areas. It successively describes the injector with its new polarized guns, some highlights of klystron research, the SLED or SLAC Energy Development Program which will boost the electron energy into the 30-40 GeV range, and some associated beam loading and beam breakup implications. Following these, a brief survey of other microwave developments is given. The paper then summarizes some of the innovations being implemented in computer control. It ends in a discussion of the changes being planned for the generation and delivery of $e^{\pm}$ beams to the PEP ring.

Present SLAC Performance

The present SLAC performance statistics are summarized in Table I.

Table I. SLAC Performance Statistics, Fiscal Year 1977

	e^+	e^-
Maximum energy	14.5 GeV	23.5 GeV
Maximum peak current (within 1% slits)		
1.6 μsec pulses	2.8 mA from 80 mA e^- incident on target [a)]	80 mA [b)]
~ 1 nsec pulses (1.5 to 2.4 GeV for SPEAR injection)	10 mA from 300 mA e^- incident on target	
Maximum repetition rate	360 pps	
Number of guns	2 conventional, 1 polarized	
Number of independent beams	8	
Number of klystrons	245	
Number of operating hours	4700 (70%)	
Number of pulses	3×10^9 (35%)	
Maximum electrical power	60 MW	
Electrical energy consumption	220 GWH	
Operating budget	$29.4 million	

[a)] Limited by maximum allowable beam power on e^+ source of 160 kW.

[b)] Limited by beam breakup.

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The maximum electron beam energy of 23.5 GeV which was obtained in June 1977 is determined by the present population of 245 klystrons with an average of 25 MW peak power per tube. With the available control system, eight independent beams with different energies and currents can be interlaced on a pulse-to-pulse basis. During a typical operating cycle of three to six months, four to six of these beams are used for fixed-target physics (spectrometers, bubble chamber, streamer chamber, large-angle solenoid spectrometer LASS, etc.), and two are permanently reserved for injection into the SPEAR storage ring. Most of the fixed-target experiments utilize e^- pulses with the best available duty cycle (1.6 μsec pulses), except for time-of-flight experiments which make use of some form of beam chopping. Occasionally, there is demand for a high energy e^+ beam. The characteristics of these e^+ beams are determined by the location of the positron source: a rotating copper "wheel" target at the end of the first kilometer along the accelerator, which gives a global e^+ yield of 10%. The actual e^+ current is limited at 180 pps to 2.8 mA peak by the power handling capability of the target (160 kW).

As for SPEAR, although colliding beams can in practice be accelerated in the ring up to 4 GeV, injection is limited to 2.4 GeV because of the design of the beam transport lines. Ring filling is achieved by two-turn injection, i.e., two ~1 nsec bursts, 781 nsec apart, each corresponding to 120° of RF phase at 358 MHz. The e^+ beam is created at the positron source, the e^- beam at the injector; both are synchronized with the SPEAR RF system. They are transported through the linac at 3 GeV and 5 GeV respectively, the final exact injection energy being obtained by 180° backphasing at the end of the accelerator. Because of the higher current and smaller phase space, the e^- beam can be injected 5 to 10 times faster (approximately 30-50 mA/min) than the e^+ beam (approximately 3-5 mA/min). The maximum repetition rate for injection is limited to 60 pps by betatron damping in the ring. Total time for injection is about 10-15 minutes. In the past year, the effective luminosity in SPEAR has been doubled by "topping off", i.e., by not dumping stored beams, but by simply replenishing them when their charge has decayed to some fraction, say 60% of the desired maximum level.

Linac utilization for physics research is characterized by the number of operating hours and machine pulses. Out of a potential maximum of ~6700 hours and 8.6×10^9 pulses per year that the accelerator complex can operate compatibly with adequate "downtime" left for maintenance and new installations, only 4700 hours (70%) and 3×10^9 pulses (35%) will be used in Fiscal Year 1977. This is due entirely to budgetary constraints that limit expenditures for klystrons, thyratrons, electrical power, etc., which are proportional to the total number of pulses. The relatively higher fraction of hours but lower pulse utilization reflects the fact that SPEAR physics, by requiring fewer linac pulses (only ~15 minutes filling time every ~2 hours), is somewhat favored over fixed-target physics, the needs of which are directly related to the number of available pulses. Hence, for economy reasons, the accelerator which has the capability of being pulsed up to 360 pps is now rarely operated at more than 180 pps.

A breakdown of the SLAC FY 1977 budget of $29.4 million, which supports the entire operating program, is given below. It shows the distribution of resources allocated to the accelerator and to physics research:

	$ Million		$ Million
Accelerator		Physics	
Operations	7.5	Facility operations	9.5
R & D	1.6	Facility R & D	3.8
		In-house research	7.0
Total	$ 9.1	Total	$ 20.3

This budget does not include funds for major accelerator improvements such as SLED or for a machine like PEP.

Injector Developments

As pointed out in Table I, the linac injector presently consists of two conventional guns and one polarized electron gun. The characteristics of the conventional guns and beam choppers are reviewed elsewhere at this conference[1] and are not covered here. The polarized gun program consists of two separate systems called PEGGY I and PEGGY II. Their principal characteristics are summarized in Table II.

PEGGY I was installed on the linac, upstream of the conventional guns, in 1974.[2] It has been in operation, on-and-off for the last 2-1/2 years, for various physics experiments. Described very simply, the source makes use of a Li^6-filled oven, heated to $\sim 1000^{\circ}C$, which emits lithium vapor through an orifice. The atomic beam so-formed first passes through a collimator and a mechanical chopper. It is then transmitted through a sextupole magnet which selects the atoms in the $2S_{1/2, m_j=+1/2}$ state. A 200 G axial magnetic field is used to align the atomic polarization longitudinally along the beam axis. The beam then travels through an intense beam of UV light from a vortex-stabilized argon flash lamp which ionizes the atoms. The electrons which are freed by ionization inherit the desired polarization, are accelerated to 70 kV and injected into the accelerator by means of a magnetic transport system. Depolarization through the 3-km accelerator has been shown to be negligible.

Ever since its inception, the PEGGY I source has undergone steady improvements (in oven loads, lamp intensity, etc.) which have increased its electron output at high polarization. A recent discovery of a resonant effect consisting of intermediate excitation into the 2P state which resulted in depolarization before final ionization, has led to the possibility of further increasing the output of the source. The increase might be obtained by using a laser with circularly polarized light at the 2S-2P resonant wavelength of 6708 Å which would selectively populate the 2P magnetic substates of desired polarization which in turn would then be ionized by the flash lamp light.

Meanwhile, interest in experiments with much higher polarized electron currents has led to the development since 1975, of a new source called PEGGY II.[3] This source is now undergoing tests which, if successful, will lead to its installation in the present location of PEGGY I (PEGGY I has meanwhile been relocated 12 m upstream). PEGGY II uses

Table II. Comparison of PEGGY I and PEGGY II Polarized Electron Sources

Characteristics	PEGGY I	PEGGY II
Electron production	Photoionization of spin polarized Li^6 atomic beam	Photoemission by circularly polarized light from Cesiated GaAs cathode
Installation on the linac	1974	1977-1978
Typical electron intensity (e^-/pulse)		
At 70 keV	$\sim 2 \times 10^9$ (obtained)	$\geq 2 \times 10^{11}$ (before installation)
At target (within 1% slits)	0.7×10^9 (obtained)	10^{11} (goal, not yet obtained)
Pulse length	1.5 μsec	1.5 μsec
Repetition rate	180 pps	180 pps
Polarization	0.85	0.44 (obtained at low current)
Polarization reversal time	3 sec	10 μsec
Light wavelength	7000 to 1800 Å (flash lamp)	7100 ± 50 Å (dye laser)
Source temperature	1000°C (lithium oven)	77°K (GaAs cathode)
Source lifetime	~175 hours per oven load	Cathode lifetime yet unknown (goal 24 hours)
Turn-around time	~40 hours for oven reload	~1 hour for cathode re-cesiation cycle

a conventional SLAC-like gun with a GaAs cathode at 77°K. A dye laser beam incident on the cathode, with ~100 watts peak of circularly polarized light at 7100 Å, raises polarized electrons from the top of the valence band to the bottom of the conduction band in the GaAs crystal. Oxygenation and "cesiation" of the cathode surface lowers its work function to the point where the polarized electrons can be emitted freely. They are then accelerated to 70 kV and transported to the accelerator, similarly to PEGGY I. Photo-emitted currents of over 50 mA peak have already been obtained, and polarization of 40% has been measured at low current. In order to provide redundancy and quick turn-around time, the source will be equipped with two identical guns. A single laser will be switchable from gun to gun when one of them fails and the other needs to be connected online. Early use of PEGGY II for an experiment is planned in Fall 1977.

In addition to these injector systems at the beginning of the accelerator, there is currently some interest in installing another conventional off-axis gun and injector around Sector 25, about 400-500 m before the end of the machine. This system would make it possible to use the SLAC accelerator for nuclear physics experiments at energies and currents (0.5 to 4 GeV, 100 mA peak) that are presently not available at other laboratories. The decision to proceed with this project has not been made.

Klystron Developments

High-power permanently focused pulsed S-band klystrons at SLAC have undergone continuous upgrading over the past ten years. Original klystrons constructed at SLAC and by industry produced 15-24 MW of peak power at 250 kV with approximately 38% efficiency. Later tubes produced by RCA and at SLAC have outputs of 30 MW. New tubes, entirely fabricated in-house, now produce 38 MW at 270 kV and have an efficiency approaching 50%. As mentioned earlier, the present klystron population on the accelerator, made up of a mix of all three types, is such that the average klystron power is 25 MW. The average age of installed tubes is 23,000 hours and the expected average MTBF may be as high as 30,000 hours.

The increase in klystron power and efficiency has resulted in additional problems which are now being studied. The klystron output window, which was very adequate at power levels up to 30 MW, can still be used at 38 MW, but the margin of safety has decreased and the window coating process must be controlled more accurately. Additional development work is also being done to improve tube life by modifications in cathode coating and processing techniques.

It is not clear that ultimate tube efficiency at 2856 MHz has yet been reached. Additional studies are being undertaken to improve gun design and focusing of electron trajectories, as well as relevant computer programs involved in klystron development.

SLED

SLED, which stands for SLAC Energy Development, is an on-going program which was started at SLAC in 1973. The SLED principle and some of its technical aspects have been described at several conferences[4,5,6] and only some of the highlights will be reviewed here.

The idea of SLED was conceived after two earlier ideas to increase the energy of the three-kilometer accelerator (through use of superconducting sections,[7] and recirculation of the beam for a second pass[8]) were abandoned for technical and economic reasons. The SLED principle is illustrated in Fig. 1 which compares the original SLAC RF-feed system (2.7 μsec pulse) with that of SLED. The SLED system makes use of a fast-acting 180° phase shifter in the input drive line, plus two identical high-Q cavities connected to the output waveguide by means of a 3-dB coupler. During the first 1.9 μsec of the pulse, a small part of the RF power is coupled to the cavities in which the fields build up, while most of the power is reflected from the waveguide/cavity interface. Because of the 90° phase-shift imparted to waves crossing the coupler slot, all of this power is transmitted to the accelerator, and none is returned to the klystron. As the energy stored in the cavities builds up, they in turn emit an RF wave which travels to the accelerator exactly out of phase with the reflected wave, thus causing the vector sum of the two waves during the initial 1.9 μsec to have the form shown in the figure.

After 1.9 μsec, i.e., 0.8 μsec or one accelerator filling time before the end of the pulse, the RF input is shifted 180°, and the emitted and reflected waves now add together (since the fields in the cavities cannot change instantaneously), producing a large power surge as shown. In theory, if the cavities were strongly overcoupled and the time available for charging were infinitely long, an instantaneous power gain of 9 could be obtained.

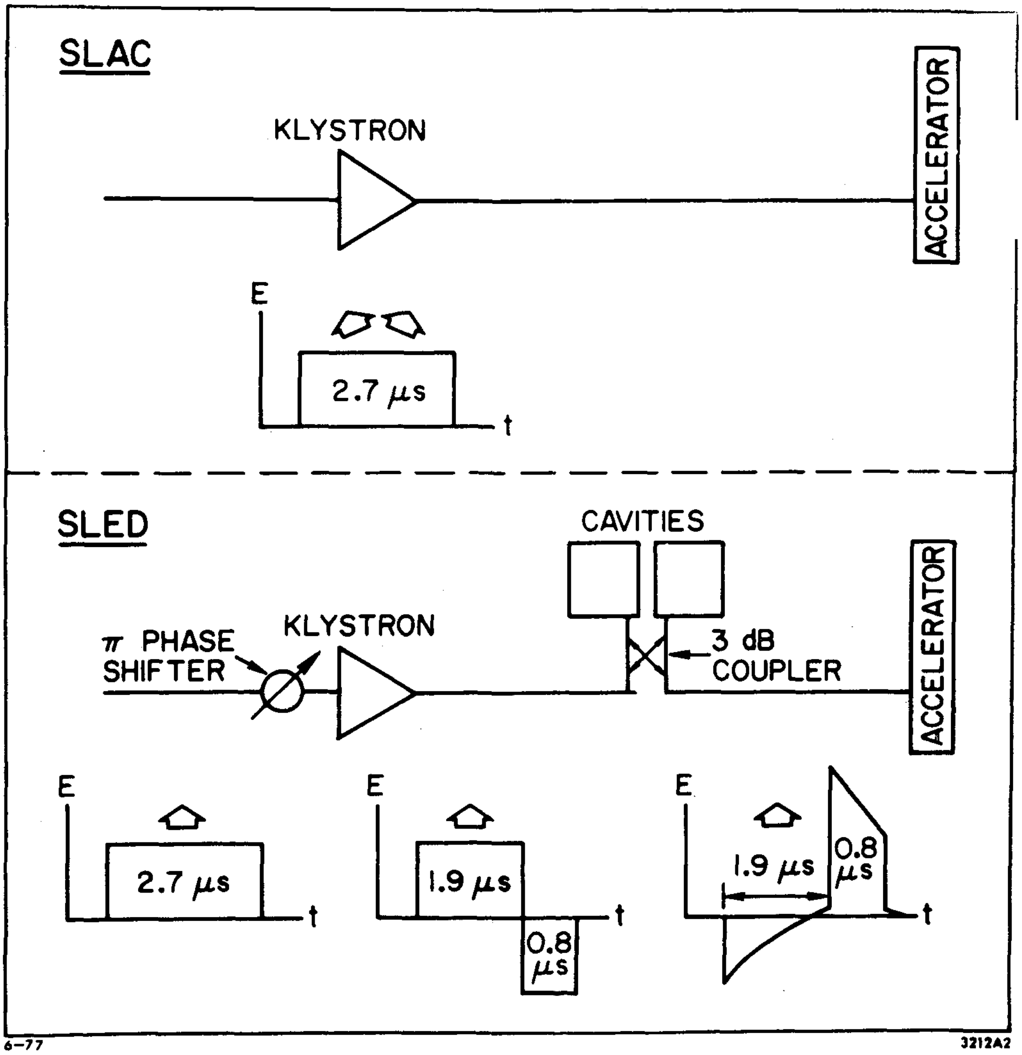


Fig. 1. SLED principle.

With the present SLAC pulse, the maximum power gain is about 4. After the phase reversal, the emitted wave decreases rapidly as the cavities try to charge up to a new field of opposite phase. After 0.8 μsec, the end of the RF pulse is reached and the remaining fields decay to zero.

The net effect of the higher power but shorter pulse is to produce an effective energy gain of 1.4 at the expense of a duty-cycle reduction by a factor of 8, with the present repetition rate of 360 pps. Implementation of this phase of the program which is now underway is called SLED I. The energy gain as a function of time, computed and measured for a complement of six sectors (45 SLEDded klystrons), is shown in Fig. 2a. The flat-top region shown on the theoretical curve is due to the finite phase-shifting time (100 nsec). Figure 2b illustrates how beam loading can be used to obtain good energy spectra with SLED. The beam pulse is timed to end at the peak of the SLED no-load energy curve, and the beam current is adjusted so that transient beam loading depresses the beam energy at the end of the pulse to equal the energy at the beginning of the beam pulse. Since the laws governing SLED energy rise and beam loading are different, the energy varies through the pulse as shown in curve A-B. It follows that use of a higher current in the first half of the beam pulse and a lower current in the second half can result in better matching and a smaller energy spread (curve A-C). In practice, a tapered current pulse may result in a good compromise solution.

The predicted operating characteristics for SLED I are shown in Table III, column 2 in contrast with the present SLAC characteristics, column 1. Notice that for optimum beam loading compensation, one will need a 200 nsec beam pulse of 215 mA. To transmit such a current through the accelerator will require additional focusing to increase the present beam breakup (BBU) threshold. This point is illustrated by Fig. 3 which shows experimental and theoretical BBU curves vs. pulse length. The two experimental curves were taken on different dates under slightly different conditions. The available focusing strength was sufficient to increase with energy only up to 15 GeV after which it was constant. The theoretical curves, scaled from the experimental ones, assume that quadrupole singlets now present in the first six sectors will be extended through Sector 10, and that power supplies will be added to the existing doublets from Sectors 11 through 30 to keep a constant betatron wavelength of 400 m through the end of the accelerator. It is seen in the upper left-hand corner that with such an improved focusing system it should be possible to reach the current levels desired.

SLED I installation began in 1975 after two years of extensive prototype development and testing on the machine. A complete assembly is shown in Fig. 4. The cavities are made of OFHC copper. They are cylindrical in shape (length = 33.59 cm, diameter = 20.51 cm), resonant in the TE_{015} mode and have Q's on the order of 100,000. In order to bypass the entire SLED operation when desirable, the cavities are equipped with detuners. These detuners consist of tungsten needles which can be inserted through a small hole in the side of each cavity. Actuation of the needles can be achieved remotely from

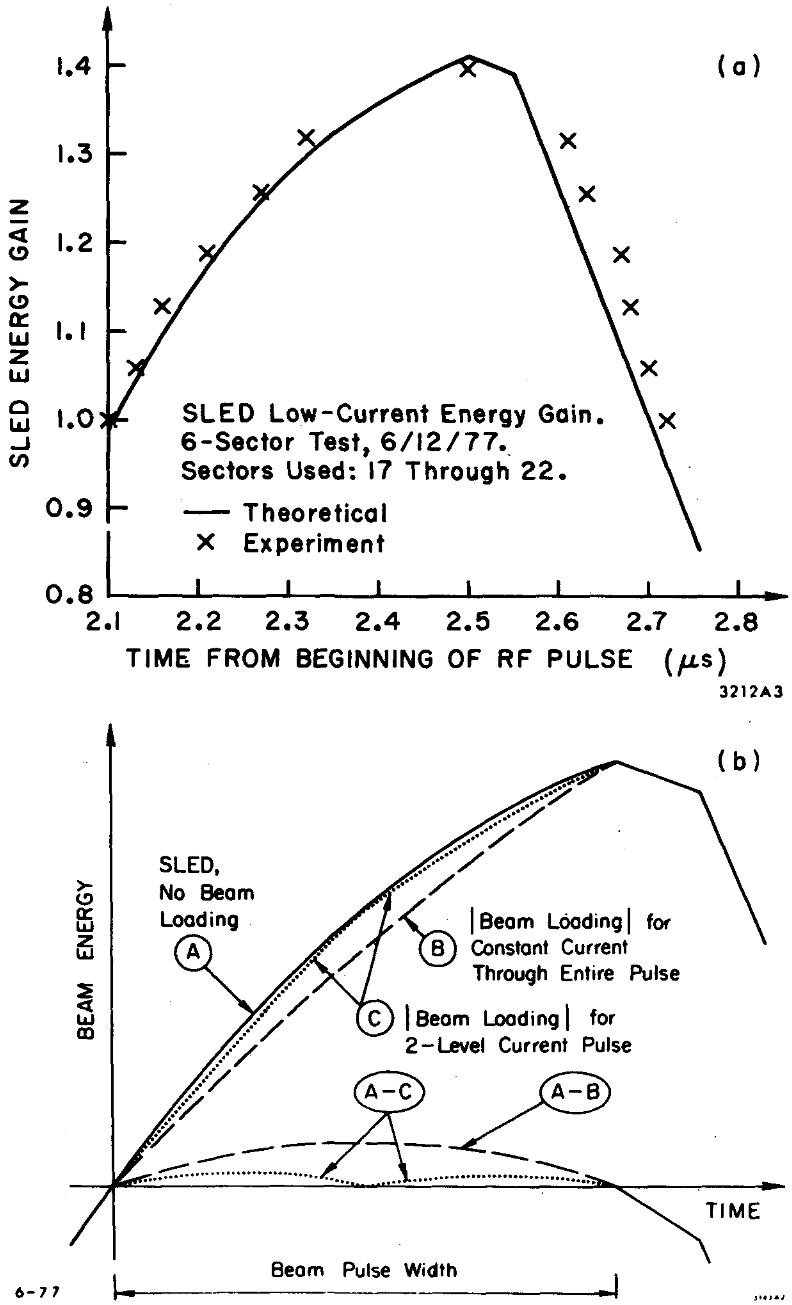


Fig. 2. (a) Experimental and theoretical SLED gain vs. time within pulse for 6 sectors. (b) Computed SLED gain with beam loading.

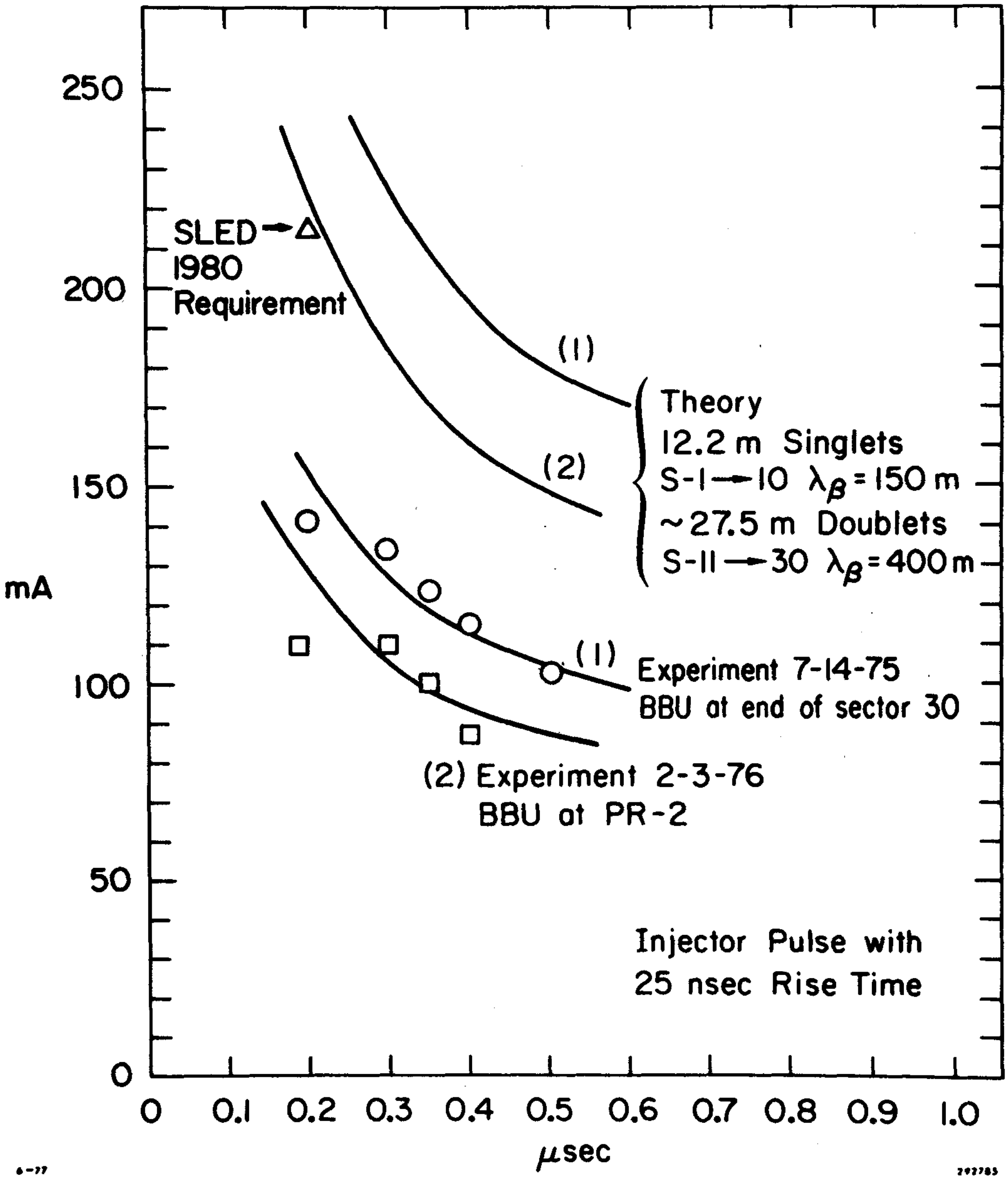


Fig. 3. Experimental and computed beam breakup thresholds vs. pulse length, and SLED current requirement.

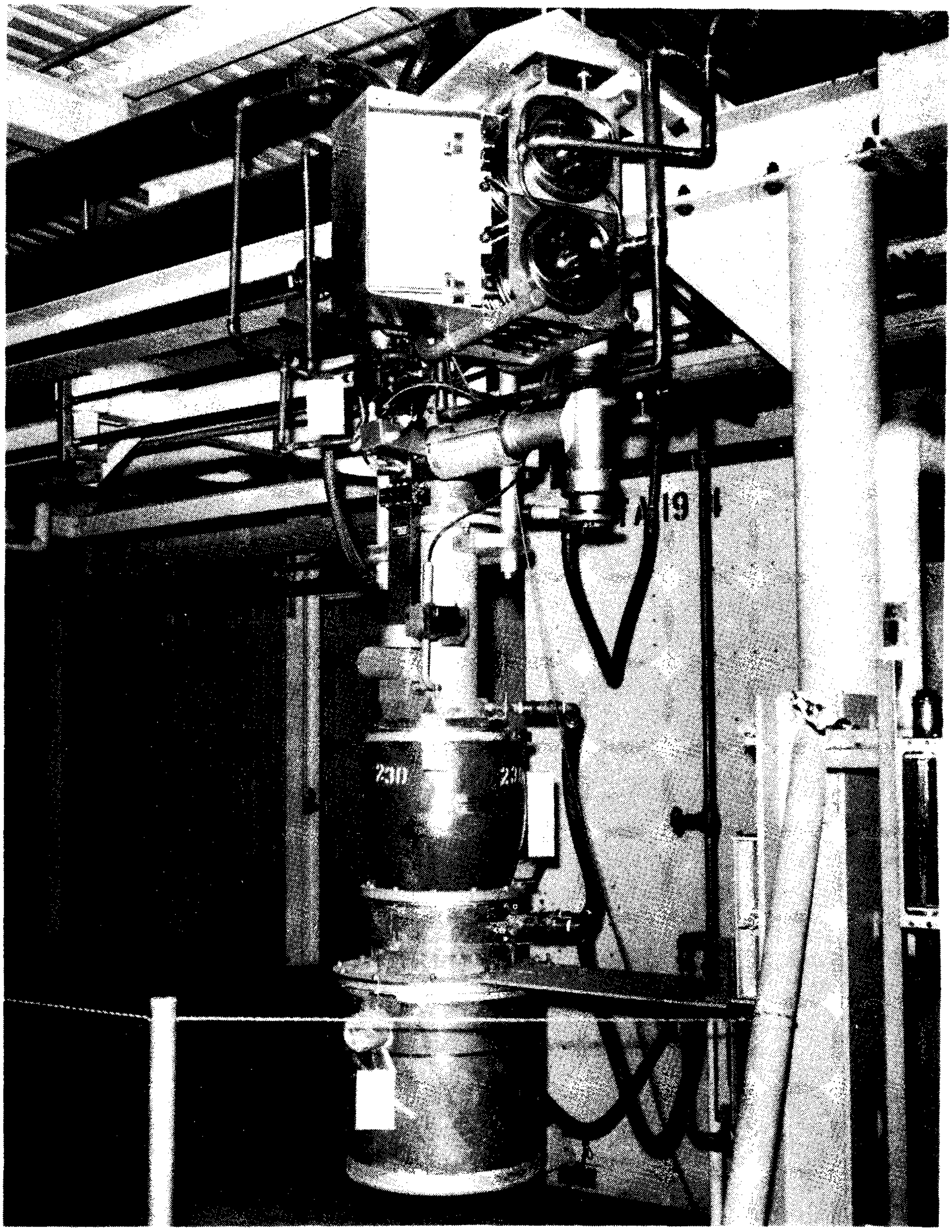


Fig. 4. Klystron with SLED cavity assembly installed.

Table III. Present and Future SLAC Energy Upgrading

	Present SLAC[a)]	SLED I[b)]	SLED I + 38 MW Klystron[c)]	SLED II + 38 MW Klystron[c)]
Maximum energy (GeV)				
No load	23	35	39	50
10% load	21	32	36	46
Duty cycle				
Maximum repetition rate (pps)	360	360	360	180
Pulse length (μsec)	1.6	0.20	0.20	0.25
Peak current				
mA	50	215	239	201
e^-/pulse ($\times 10^{10}$)	50	27	30	32
Cumulative cost ($\$ \times 10^6$)	--	6.1	9.1	12.6
Years to complete	--	3	2[d)]	2[d)]

Klystron Population Mix	20 MW	30 MW	38 MW
a) Present	113	93	37
b) Assumed in 1980	55	69	119
c) Later	--	--	243

d) Years after completion of SLED I.

the Main Control Center, so that the changeover from conventional to SLED operation and vice-versa can be accomplished in a matter of minutes. At the present time, SLED equipment has been installed in 8 of the 30 accelerator sectors. The remaining installation work will proceed in increments through the scheduled completion date of January 1980. The total cost of the SLED I program during this period will be about \$ 6.1 million, of which \$ 4.3 million is associated with the microwave cavities and \$ 1.8 million with pulsed focusing and new beam switchyard magnets to handle the higher energy beams.

Note in Table III that the maximum beam energy achieved is determined both by the SLED-related energy increment and also by the population mix of different klystrons in use on the accelerator at the time specified. As the existing 20 MW and 30 MW klystrons fail, they are replaced by 38 MW tubes referred to earlier. The footnote in the table shows the present mix of 20, 30 and 38 MW tubes on the machine, the mix predicted for 1980 when SLED I is completed, and also at an unspecified future time when all of the present 20 and 30 MW tubes will have been replaced with 38 MW models. At such a future time, SLED I would reach its ultimate performance, as shown in column 3 of the table. This eventual result could be achieved either through the continuing gradual program of replacing failed klystrons with 38 MW tubes, or through a more rapid program specifically designed to retire the older klystrons before failure and to substitute the more powerful tubes.

Upon completion of SLED I, it may be possible to lengthen the klystron-modulator pulse up to 5 μsec by doubling the number of capacitors in the present pulse-forming networks and replacing the existing pulse transformers. Upon completion of this phase of the program called SLED II, the energy multiplication factor would be 1.8 but the repetition rate would have to be dropped to 180 pps to keep the total ac power consumption at its present level. The no-load energy of the linac could reach 50 GeV. Other characteristics of SLED II including total cumulative costs (SLED I + 38 MW klystrons + BSY improvements) are shown in Table III, column 4. Whether the SLED II option will be exercized is unknown at this time.

Other Microwave Developments

There are three other microwave developments which are worthwhile mentioning. The first one concerns new beam position monitors.[9] Table IV gives a summary of all such monitors presently in use at SLAC. The first column lists three different signal processing schemes used with the standing-wave assemblies which comprise one TM_{010} reference cavity and two TM_{120} cavities (x and y). The first scheme, used on 30 monitors along the machine, is based on detection at 2856 MHz, i.e., the accelerator frequency. It has been in use for over ten years with thermionic diodes which in the near future will be replaced by more reliable hot-carrier diodes. The second scheme, used in the beam switchyard (BSY), is based on 60 MHz receivers and detectors and it works for peak currents down to 0.1 μA. No signal normalization has been attempted and the output is displayed in video form. The third scheme, used to measure ultra-small displacements for moderately low-current experiments, is based on 30 MHz phase-modulation and detection. The system is of the so-called homodyne type in which the position signal is modulated by 180° with a double-sideband suppressed-carrier (DSSC) modulator.

The second column shows a traveling-wave monitor in the simple form of a short stub of nonresonant rectangular waveguide (identical y-monitor not shown). The signal processing uses mixers and 60 MHz limiting amplifiers which conserve the phases of the input signals but make the outputs independent of current amplitude. This monitor is being used for medium and low-current experiments for which the beam must be swept by large but precise displacements across a low-temperature polarized proton target.

The second microwave development is a scheme to rapidly compensate for transient beam-loading which at high currents leads to "gulches" in the energy spectrum. For this purpose, the standard 1.6 μsec beam pulse is divided into eight 0.2 μsec segments during which a preprogrammable digital phase shifter can change the phase of one accelerator sector (8 klystrons) by stepped increments. The phase modulation results in rapid energy modulation which has been used successfully on an experimental machine run. A practical system is now being built.[6]

The third microwave development is a new high-precision method to monitor pulse-to-pulse and short-term energy changes on the accelerator.[10] The scheme is based on the fact that the path length and hence the bunch "flight time" through the BSY varies with energy (17 picoseconds or 17 electrical degrees at 2856 MHz per 1% in energy). By comparing the phases of beam-induced cavity signals at both ends of the switchyard, it has been possible to measure shifts in energy to a precision of 0.01%.

Instrumentation and Control

The instrumentation and control system on the SLAC linac has evolved considerably since beam turn-on in 1966. From a largely hardwired system controlled from two separate control rooms with only one computer (the XDS-925 for the BSY), it has grown into the much more complex system shown in Fig. 5. This evolution has been driven by two major forces: the desire to centralize control at one point, and the need to set up and operate a much greater diversity of beams.

The decision to consolidate the Central Control Room (CCR) and the Main Control Center (MCC) into one location in MCC to streamline operations was firmly made in December, 1969. The need to produce a greater diversity of beams came gradually as the number of experiments to be done at SLAC increased, particularly with the inception of SPEAR in April, 1972. Installation of the PDP-9 in CCR in 1968-1969 followed by connection of the link with the XDS-925 and the "touch panels" in MCC in 1971[11,12] lead to early operation from MCC alone by May, 1972. This embryonic system, capable of central but relatively slow control of 6 simultaneous beams, was much improved by 1973-1974 after a string of 9 PDP-8's had been deployed along the accelerator.[13,14] These PDP-8's made it possible for several operators to: (1) initiate and execute parallel commands from MCC, (2) operate multilevel devices, like for example, pulsed steering, which for 6 parallel beams had to be settable to as many as 6 different levels on a pulse-to-pulse basis, and (3) receive analog readout displays for all these devices on the touch panels.[15,16] In the period 1975-1976, two new plans began to emerge. One was the decision to gradually replace the XDS-925, which after 10 years is becoming obsolete, by three PDP-11/24's. Two of these are now coming into service as shown in the figure, while the third one, which will assume the control functions of the XDS-925, will be procured in 1978. One of its new functions will be to interface with the PEP computer complex to automate linac beam injection into the new ring. The other plan was to upgrade individual systems by allowing old hardware controllers to be replaced by modern microprocessors. The figure shows three such examples along the accelerator,[17] all to be operable through the PDP-8's: (1) the trigger system which governs the time when klystrons and other devices are triggered (at beam-time, standby-time, or not at all), and which through use of the microprocessor will attain much greater flexibility; (2) the phasing system which sets individual klystrons to the proper phase with respect to the beam, and which in the future should achieve its tasks on a quasi-noninterfering basis; and (3) the beam guidance system which sets beam steering and focusing levels, and which in the future will be able to accommodate as many as eight different beams on a pulse-to-pulse basis. It will take about two years to complete the engineering and installation of these microprocessor systems along the accelerator.

Another aspect of instrumentation and control which has developed greatly in the past few years is the beam containment system. Inception of this system dates back to 1971 when it became clear that no single mechanical device could be relied on to contain up to

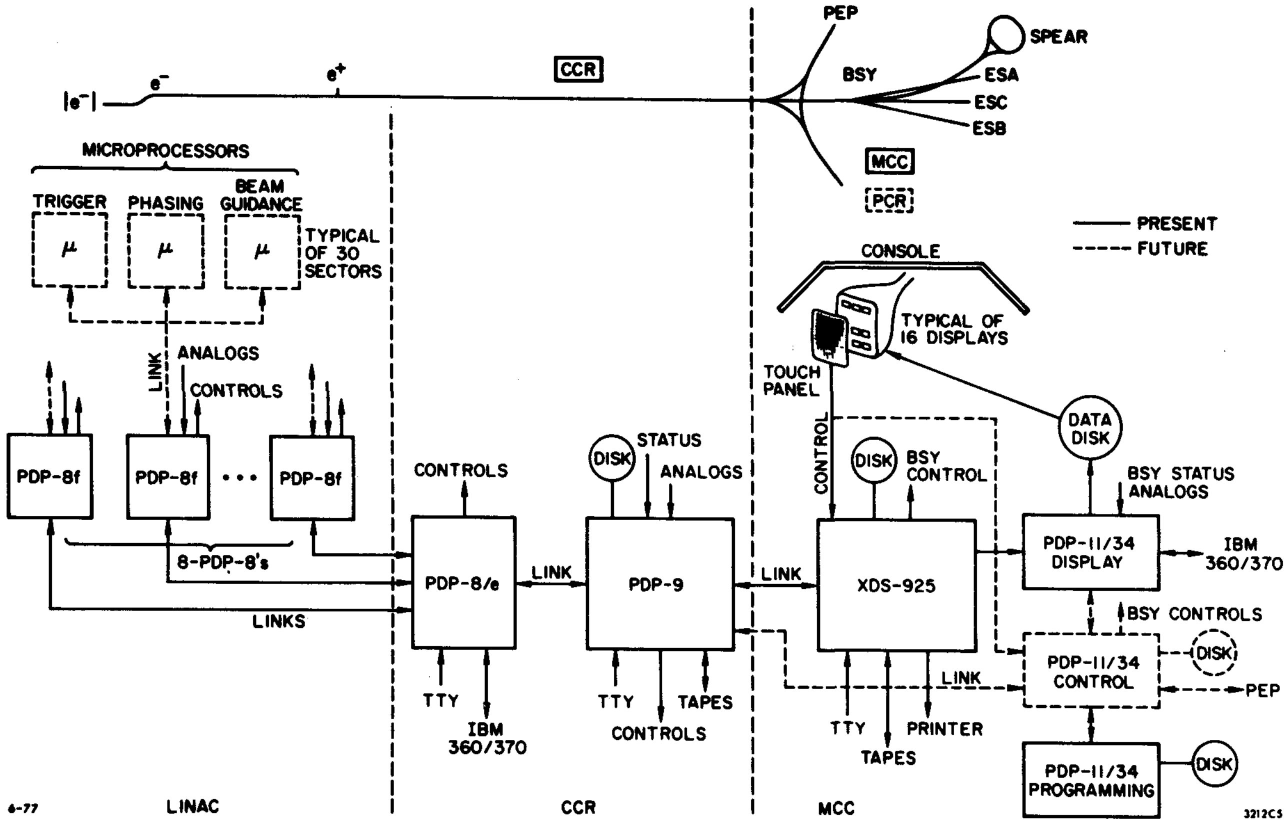


Fig. 5. Present and future computer control.

~800 kilowatts of beam power for more than a few seconds. The beam containment system which uses detectors and electronic comparators to verify that beams of various currents and repetition rates leave and arrive at predetermined destinations is described in detail in Ref. 18.

Generation and Delivery of $e^{\pm}$ Beams to PEP

It is planned that both e^+ and e^- beams for PEP will be injected at the operating energy of the ring (4 to 18 GeV). As is done for SPEAR, the e^- beam will be generated at the injector, the e^+ beam at the positron source in Sector 11. With the advent of SLED, positron energies up to 18 GeV will easily be reached. Each beam stored in PEP will consist of three bunches spaced 2.4 μsec apart. The linac pulses will be chopped to ~1 nsec to fit within the three corresponding RF buckets. They will be synchronized with the PEP RF frequency (353 MHz) and time-multiplexed among the three bunches so as to bring their charges up as simultaneously as possible. It is estimated conservatively that linac beam delivery rates within 1% spectrum will be $\sim 0.7 \times 10^8$ e^+/pulse (10 mA peak) and $\sim 0.7 \times 10^9$ e^-/pulse (100 mA peak). Up to 15 GeV, the stored current in PEP will vary as 2.5×10^{12} $(E_{GeV}/15)$ $e^{\pm}$. Thus, the numbers of required linac pulses will be ~36,000 $(E_{GeV}/15)$ for e^+ and 3600 $(E_{GeV}/15)$ for e^-. At 4 GeV, using the wiggler magnets, the damping time will be such that the allowable linac repetition rate will be 36 pps. At 12.5 GeV and above, it will be 360 pps. The resulting filling times for e^+ and e^-, not allowing for any inefficiencies, will vary from ~5 minutes at 4 GeV to ~2 minutes at 15 GeV and above. Practical times including tune-up could be somewhat longer but present plans[19] to upgrade the positron source to increase both its yield and energy spectrum may in turn make up for these inefficiencies.

Figure 6 shows the e^+ transport line (the e^- line has mirror symmetry with respect to the linac). Each transport system[20] is composed of three achromatic bend segments, two approximately horizontal and one vertical (the horizontal segments are rolled 6° about the SLAC axis so as to bring the beams down to the lower elevation of the ring). Three standard pulsed quadrupoles are used at the end of the linac to match the $e^{\pm}$ beam emittances to the acceptances of the injection lines. Two pulsed dipoles deflect the beams 5.5 mrad downward into the B1 dc Lambertson septum magnet. All other SLAC beams, which are undeflected, remain unperturbed. At this point, the e^+ and e^- beams become horizontally separated. The bends in B1 and B2 are 3.75° each, 7.5° in B3 through B9, and 2.4° in B10 and B11. The dc quadrupoles, spaced 8.5 m apart, form a simple FODO array with a 90° betatron phase shift per unit cell. Dispersion at the slit between Q-2 and Q-3 is to be 3 cm/%$\Delta E/E$. In addition to standard instrumentation, the e^- line is equipped with a short-beam gate consisting of 2 pulsed kicker magnets, a permanent magnet and a protection collimator which prevent a long 1.6 μsec linac pulse from accidentally entering the ring and producing radiation damage. To match the η'-function at the ring $(dx'/d(\Delta p/p))$, the Q-13 and Q-17 quadrupoles which are separated by a (-I) matrix transformation, can be varied in opposing sense, without varying the η-function or the

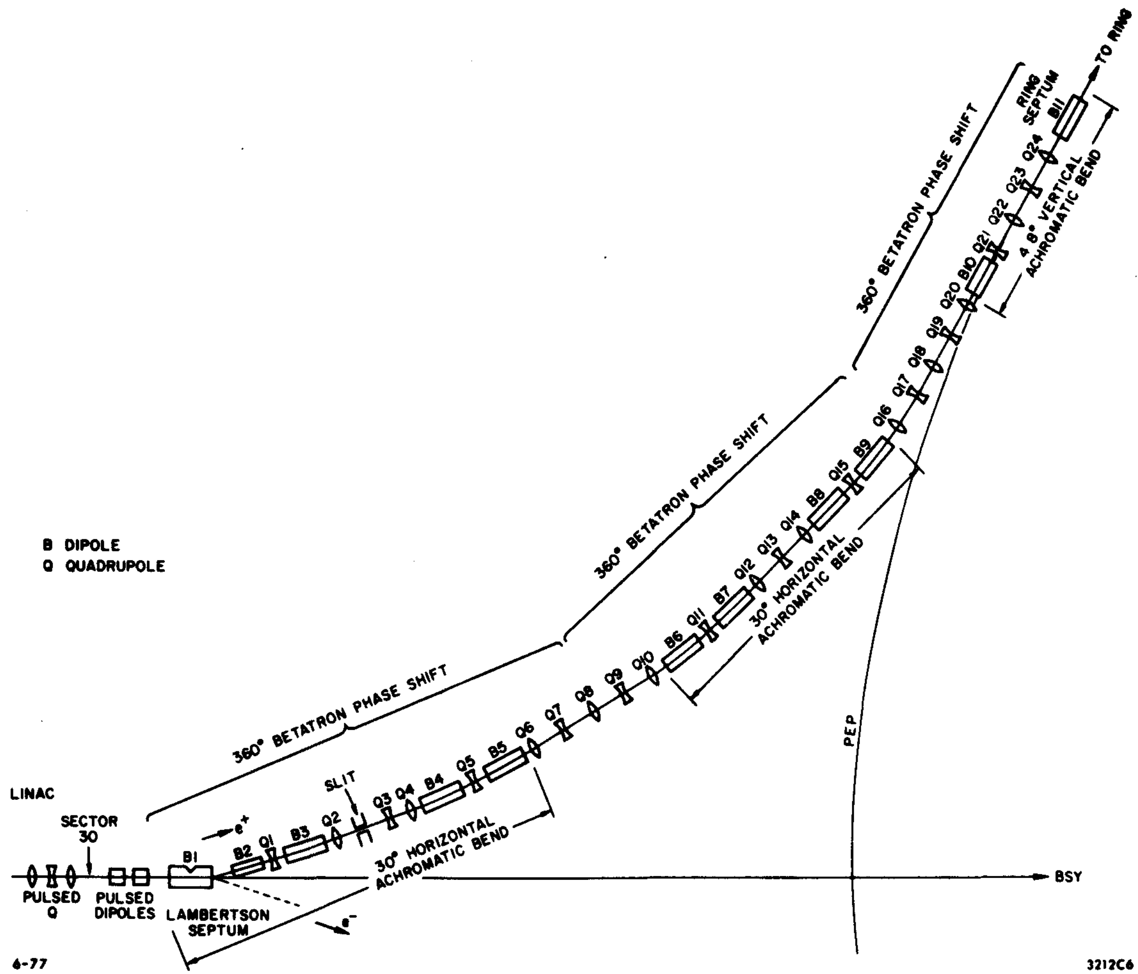
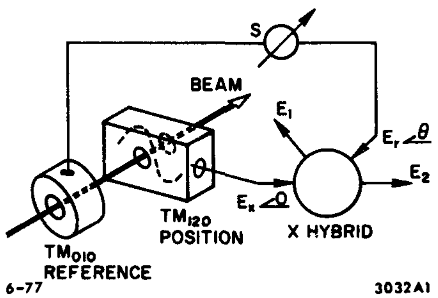
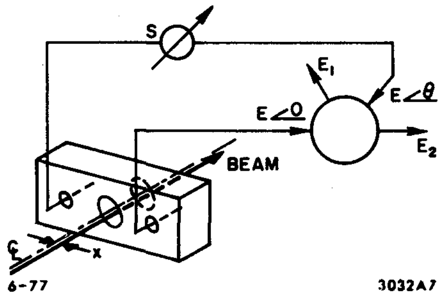


Fig. 6. Beam transport system from linac to PEP.

Table IV. SLAC Beam Position Monitors

Type	Standing-Wave Assemblies (resonant)	Traveling-Wave Assemblies
Microwave layout		
Signals to be processed	$E_r \sim I$ $E_r^2 \sim 250$ mW/mA^2 $\bar{E}_2 - \bar{E}_1 \sim Ix, Iy$ $E_x^2 \sim 50\ \mu$W/mA^2 mm^2	$\bar{E}_2 - \bar{E}_1 \sim Ix$ $E^2 \sim 250\ \mu$W/mA^2
Processing for accelerator monitors	Detection at 2856 MHz Thermionic diodes (to be replaced by hot-carrier diodes) Normalization: $\frac{\bar{E}_2 - \bar{E}_1}{E_r} \sim x$ achieved by log amplifiers. Resolution: 1 mm for $0.5 < i < 40$ mA	Not used in accelerator
Processing for BSY monitors	(a) Detection at 2856 MHz Thermionic diodes Resolution: 1 mm for $0.5 < i < 40$ mA Hot-carrier diodes Resolution: 1mm for $0.1 < i < 0.5$ mA (b) Mixers and 60 MHz I.F. amplifiers Local oscillator at 2796 MHz Resolution: 1 mm for $i \geq 0.1\ \mu$A	Not used in BSY
Processing for very low-current monitors for experimental beams	180^o phase-modulation of position signal and synchronous detection at 30 MHz Local oscillator at 2856 MHz Resolution: 10 μm at $i \geq 100\ \mu$A	Mixers and 60 MHz limiting I.F. amplifiers Local oscillator at 2796 MHz Normalization achieved by limiters on E^2 Sensitivity: 2^o per mm Resolution: 0.1 mm at $i \geq 20\ \mu$A

monoenergetic phase ellipses in the x and y planes at the injection point. Design apertures are ±25 mm (horizontal) and ±10 mm (vertical). Injection into the ring is achieved by standard techniques using three pulsed kickers and a dc Lambertson septum.

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ДИСКУССИЯ

A.A.Kolomensky: What is the main reason which limits the multiplicity of power at SLED?

G.A.Loew: There are basically two factors limiting SLED energy gain: the available RF pulse length and the intrinsic losses in the cavities. If we had a very long RF pulse and very low loss cavities, the emitted field from the cavities could be made twice as large as the klystron field reflected off the cavities. The maximum instantaneous power would then be $(2+1)^2$ or 9 times the klystron power. In practice the effective power gain is only 2 to 3.2 with the parameters available at SLAC and the energy gain 1.4 to 1.8. One could, indeed, obtain higher numbers by cascading several sets of cavities.