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The Advanced Photon Source (APS) Linear Accelerator - Design and Performance*

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Abstract. The Advanced Photon Source (1) linear accelerator (linac) system consists of a 200-MeV, 2856-MHz S-band electron linac and a 2-radiation-length-thick tungsten target followed by a 450-MeV positron linac. The linac system has operated 24 hours per day for the past two years to support accelerator commissioning and beam studies, and to provide beam for the experimental program. It achieves the design goal for positron current of 8 mA, and produces electron energies up to 650 MeV without the target in place. The linac is described, and its operation and performance are discussed.

INTRODUCTION

The linac is the source of particles, either electrons or positrons, at the APS. It is designed to accelerate 30-nsec-long pulses containing 50 nC of electrons to an energy of 200 MeV at 48 pulses per second. The 480-W beam is focused to a 3-mm diameter spot on a 7-mm-thick water-cooled tungsten target that serves as a positron converter. Bremsstrahlung-pair-produced (BPP) positrons and electrons are refocused by a 1.5-T pulsed coil and are directed into the positron linac. Both electrons and positrons are captured and can be accelerated to about 450 MeV. The final optimization is achieved as a result of rf phasing and steering.

DESCRIPTION

Electrons are emitted from a thermionic cathode in the electron gun and exit the gun at a nominal energy of 100 keV. They are transported to a prebuncher cavity that bunches the beam longitudinally at 2856 MHz before it enters the buncher. The buncher is a short piece of disk-loaded waveguide that further compresses the beam bunches to allow for efficient capture and acceleration in the rest of the linac. Beam exits the buncher with an energy of about 4 MeV and enters the first of fourteen 3-m-long, traveling-wave, constant-gradient SLAC-type accelerating structures that accelerate particles through the rest of the linac. Rf power at 2856 MHz, provided by klystron amplifiers, enters the disk-loaded accelerating structures via input-coupler cells and couples to adjacent cells through holes in the center of the disks. Dimensional changes in the individual cavities keep the axial electric fields constant over the entire length of the structure and compensate for

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power losses to the walls. Coupling cells at the output ends of the structures direct the remaining rf power into water-loads to be dissipated as heat and carried away by the cooling system. Details of the injection end of the linac are shown in Figure 1. There are five accelerating structures in the electron linac and nine in the positron linac. The upstream accelerating structure in each linac is directly powered by a 35-MW klystron, while the remaining 12 structures are powered in groups of four by a klystron and SLED cavity assembly, as shown in Figure 2. Power to the klystrons is provided by 100-MW line-type pulse modulators (2). All accelerating structures, SLED cavities, and waveguide components are held at a constant temperature (± 0.1°F) to maintain cavity dimensions and improve energy stability.

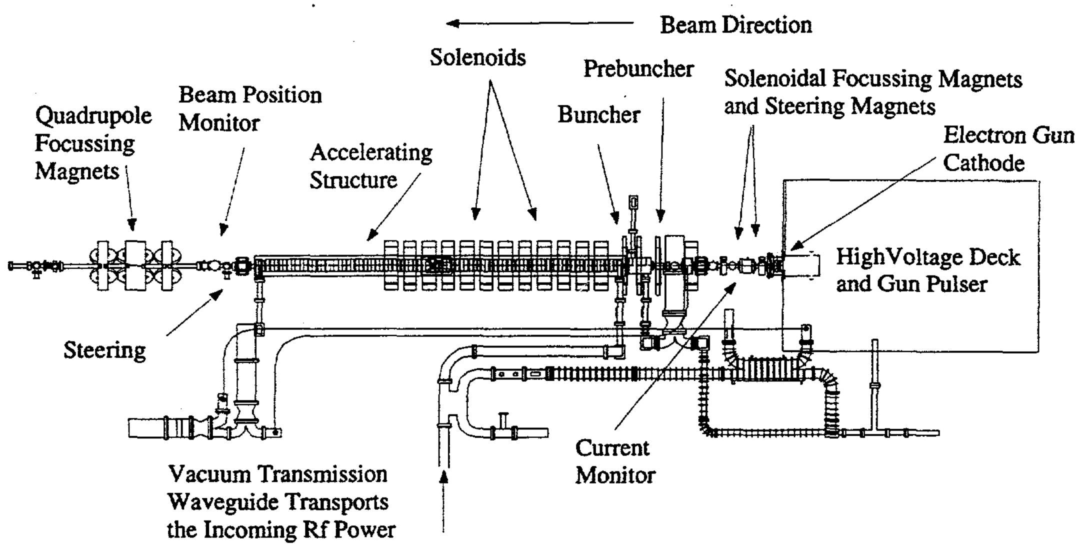

FIGURE 1. Schematic view of the injection section of the linac.

Beam current is measured by a toroidal coil and three ceramic-break detectors. Beam position in the linac is measured by eleven 4-button stripline beam position monitors (3) that also measure beam current. Information on current and position, together with beam profile information, is used to establish the optimum settings for the 42 focusing and 38 steering magnets that enable the beam to be transported though the linac. Fourteen gas-filled particle detectors run the entire length of the linac and allow areas of high beam loss to be localized. Beam profile information is obtained by inserting fluorescent screens that are viewed by cameras (4) into the beam. Real-time beam images are visible in the control room, and digitized information is collected and analyzed via the controls system.

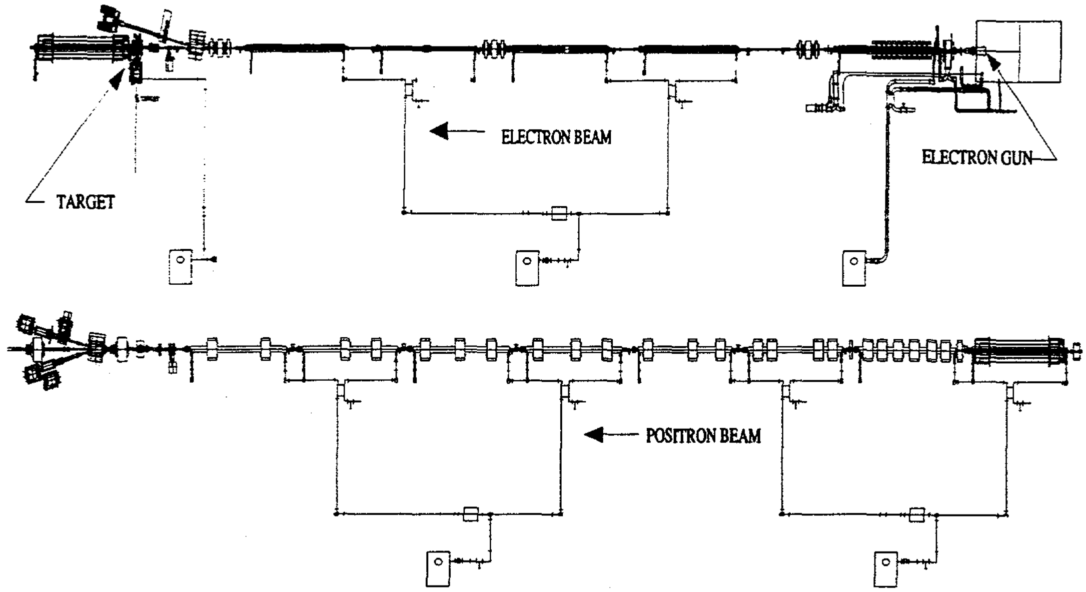

FIGURE 2. Schematic view of the entire linac. The electron and positron linacs have been drawn parallel to each other for clarity, and the two scales are slightly different.

A basic operation in setting up the linac is to establish the correct phase relationship between klystrons. This is accomplished using the diagnostic lines at the end of each of the two linac sections (see Figure 2), where a dipole magnet bends the beam out of the linac and onto a fluorescent screen. The beam energy is calculated from the dipole current. The width of the beam image on the fluorescent screen depends on the energy spread. Phase is easily optimized by minimizing the energy spread and maximizing the energy, whilst viewing the beam image. The proper phase is then maintained by automatic phase control software (5,6).

Electrons transported from the gun to the end of the positron linac reach an energy of more than 650 MeV. The APS storage ring is being commissioned with electrons for reasons of simplicity and injector reliability. Positrons will be used in normal operation to avoid ion-trapping instabilities that can otherwise result when heavy positive ions accumulate around the electron beam. The 200-MeV, 480-W beam at the end of the electron linac is focused to a 3-5-mm spot and impinges on a 7-mm-thick water-cooled tungsten target. Both positrons and electrons are produced by bremsstrahlung pair-production, with a conversion rate of about 1 pair per 200 incident electrons. Both polarities are accelerated in the positron linac, one in each half-cycle of the electromagnetic wave. If phasing is chosen to optimize positrons, the electrons then fall into the next available bucket and are accelerated, but with a somewhat larger energy spread and slightly lower energy. The data in Figure 3a were obtained by using the dipole magnet to sweep the beam, optimized for positrons, across the two Faraday cups at the end linac, shown in Figure 3b. The positrons have higher energy and lower energy spread than the electrons. Table 1 lists a summary of the achieved linac performance.

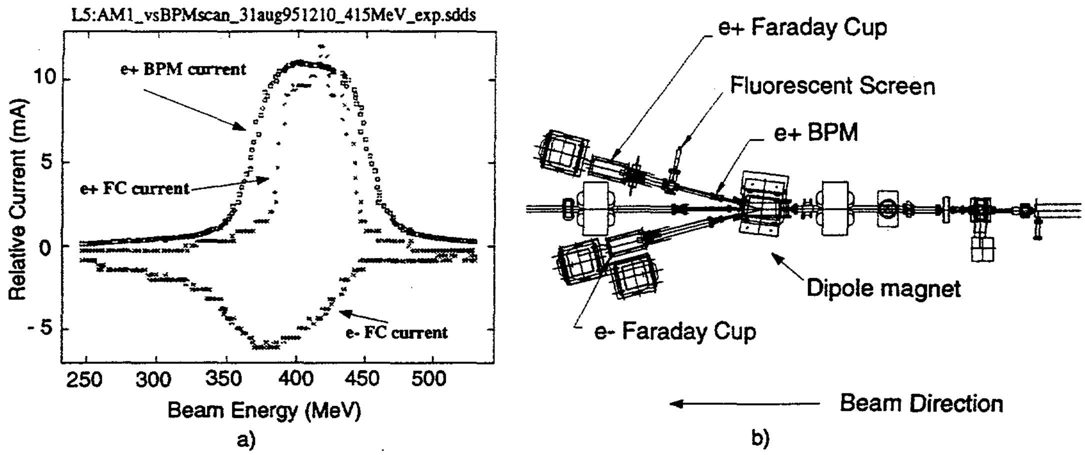

FIGURE 3. Electron and positron energy and energy spread with beam optimized for positrons (a). Data were collected by sddsexperiment (9). Diagnostic line at the end of the linac (b), showing Faraday cups, dipole magnet, and a BPM.

TABLE 1. Linac Performance Summary

Electron Linac	Design Goal	Achieved	**Positron Linac**	Design Goal	Achieved
e-					
Energy on Target	200 MeV	240 MeV	**e +**		
Pulse Length	30 ns	30 ns	Energy	450 MeV	454 MeV
Target Spot Size	φ ≤ 3 mm	φ ≤ 5 mm	Current	8 mA	14 mA
Power on Target	480 W	390 W	Energy Spread	± 1 %	≤ ± 1.6 %
Current on Target	1.7 A	> 2.0 A			
Repetition Rate	48 pps at a 60-Hz rate	Beam: 30 Hz Rf: 60 Hz			
Maximum Energy	650 MeV	> 655 MeV	**BPP e-**		
Energy Spread	± 8 %	≤ ± 8 %	Energy	Unplanned	> 400 MeV
Emittance (mm mrad)	≤ 1.2	≤ 1.2	Current	Unplanned	> 17 mA

Radiation levels in the linac are extremely high during operation, especially near the conversion target. All linac systems capable of producing or accelerating beam are therefore interlocked to the personnel safety system. These systems are deactivated by two independent chains by doubly redundant methods whenever the tunnel is open for access or when beam permissive is removed for any reason. The linac tunnel is constructed with 2-m-thick walls supplemented by 16" of steel near the target. Penetrations in the shield wall that permit passage of transmission waveguides, cables, water, and other utilities are individually shielded, and are frequently monitored to ensure that there is no abnormal radiation leakage. Radiation levels in all areas near the linac are within DOE guidelines (7).

The linac is controlled by the Experimental Physics and Industrial Control System (EPICS) (8). The EPICS system is extremely flexible and when combined with the sdds toolkit (9), provides a powerful environment for monitoring as well as active and passive control of the accelerator and its various subsystems.

SUMMARY

The APS linac has been operational for two years and has met its design goals. It operates 24 hours per day to produce 400-MeV electrons for the purpose of commissioning other APS accelerators. Positrons are used in linac and low energy transport line studies but will be injected into the positron accumulator ring, booster synchrotron, and storage ring in a few months.

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