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Conf-9408125--28 ANL/ASD/CP--82443

Status of the Advanced Photon Source (APS) Linear Accelerator *

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Abstract

A 2856-MHz S-band, electron-positron linear accelerator (linac) has been constructed at the Advanced Photon Source (APS). It is the source of particles and the injector for the other APS accelerators, and linac commissioning is well underway. The linac is operated 24 hours per day to support linac beam studies and rf conditioning, as well as positron accumulator ring and synchrotron commissioning studies. The design goal for accelerated positron current is 8-mA, and has been met. Maximum positron energy to date is 420-MeV, approaching the design goal of 450-MeV. The linac design and its performance are discussed.

I. INTRODUCTION

The electron linac's injector consists of a thermionic gun, a single gap prebuncher, a constant impedance buncher with $v_p = 0.75c$, and a 3-meter-long constant gradient travelling wave accelerating structure. The prebuncher, buncher, and accelerating structure are powered by a single klystron. Rf power from a second klystron is transmitted to a SLED [1] cavity assembly. The SLED compresses the rf power in time, proportionally increasing the peak power. The shorter but higher peak power pulse is split four ways, powering the other four accelerating structures in the electron linac. A dipole magnet at the end of the electron linac allows visual energy and energy spread optimization and energy analysis to be performed using the diagnostic line's [2] fluorescent screen.

Thirty-nanosecond-long pulses from the electron gun are accelerated to at least 200 MeV by the electron linac at up to 60 pulses per second. The electron beam is focused by a quadrupole triplet onto a 2 X_0 (7-mm) thick water-cooled tungsten positron conversion target. Radiation shielding is incorporated into the target housing providing some protection for upstream and downstream components. The desired spot size on the target is ≤3-mm, and a ≤5-mm spot size has been achieved to date. Beam positioning and focusing on the target are aided by beam diagnostics and a beam profile analysis package.

A pulsed solenoidal coil just downstream of the target produces a 1.5-T field, focusing the beam into the positron linac where nine more accelerating structures accelerate the positrons (and electrons). The first two accelerating structures are surrounded by solenoidal magnets (B=0.3T) for focusing and containment of the low energy beam, and the final seven are surrounded by 24 FODO quadrupoles. Steering magnets are positioned throughout the linac. The positron linac is powered by three klystrons and two SLEDs as shown in Figure 1; the maximum positron energy to date is 420 MeV. A dipole magnet is installed at the end of the linac, allowing positron energy optimization and energy analysis to be done visually on a fluorescent screen. Electron and positron Faraday cups are located after the dipole (see Figure 2), and simultaneous readout of positron and electron currents allows for positron current optimization.

The linac beamline is shown in Figure 3. Design goals and measured results are listed in Table 1 for some linac parameters.

Table 1
Electron and Positron Linac Beam Parameters
Measured Result and (Design Goal).

	e^- Linac	e^+ Linac
Energy	230(200)-MeV	420(450)-MeV
Pulse Rate	10(48)-pps	10(48)-pps
Pulse Length	30(30)-nsec	30(30)-nsec
Particles/Pulse	2.21(3.13) x 10^{11}	1.10(1.56) x 10^9
Charge/Pulse	35(50)-nC	0.25(0.25)-nC
Beam Current	1.2(1.7)-A at tgt	8(8)-mA
Beam Power (W)	81(480)	≈8[e^++e^-](5.4e^+)
Beam Emittance 95% π-mm-mrad	≤ 1.2 (≤ 1.2)	(6.6)
($\Delta E/E$)	≤ ±8% (±8%)	±3% (±1%)

II. RF SYSTEM

Klystron amplifiers (Thomson TH 2128) are powered by line type pulsed modulators [3] which provide 100-MW peak power to the klystrons at repetition rates up to 60 Hz. Regulation is done with a command charge tetrode system. Thirty MW of rf power at 2856 MHz is fed into the accelerating structures, producing an electric field gradient of about 20 MV/m.

The 2856-MHz low level output of a highly stable master oscillator is amplified by a 10-W GaAs FET amplifier, and is then divided into two separately distributed signals. One of these signals is distributed to the five klystron drivers, and the other provides the reference to the VXI-based phase measurement system.

The klystron driver uses a GaAs FET preamplifier followed by a 400-W pulsed driver amplifier [4]. The pulsed driver amplifier is based on bipolar transistor technology.

*Work supported by the U. S. Department of Energy, Office of Basic Sciences, under the Contract W-31-109-ENG-38.

III. Beam Diagnostics

Eleven beam position monitors (BPMs) [5], three wall current monitors, and eight fluorescent screens [6], measure the beam's position and current. Gun current and pulse width are measured by a toroidal current monitor located just downstream of the electron gun. Stripline BPMs measure the beam's position and intensity both horizontally and vertically. Measured sensitivities are 1.75 $\pm$ 0.15dB/mm. Relative position is obtained using log-amplifier electronics and is measured to be $\pm$ 50μm. It is limited for now to $\pm$12μm by a 12-bit analog-to-digital converter. Beam intensity calculated from the BPM output is available to operators, and allows for fast optimization of the trajectory. The beam's relative position, spot size, and shape are measured by fluorescent screens. The video image is frame grabbed, processed, and displayed. The resulting image is accurate to approximately 600μm. BPMs, fluorescent screens, and current monitors are installed throughout the linac.

IV. Readout and Controls

The linac control system uses the Experimental Physics and Industrial Control System (EPICS) tools which have been developed by the Controls and Computing Group at APS/ANL and by the AOT-8 Group at LANL [7]. Eight microprocessor-based Input/Output Controllers (IOCs) provide real-time control, monitoring, and data acquisition services to the linac equipment. Two IOCs accommodate the beamline equipment, including vacuum, magnets, and cooling water. Each of the five rf stations has a dedicated IOC which acquires its rf and diagnostic measurements at a 60-Hz rate. An eighth IOC handles the image processing requirements for the fluorescent screen cameras. The IOCs are connected to a common ethernet thru which they can communicate with each other and with the Unix-based Operator Interface workstations (OPIs). Tools for interactive equipment control, data archiving, alarm management, and backup/restore of machine settings have been developed.

Beam diagnostics readout and rf phase and amplitude measurements have been integrated, together with the dedicated microprocessor-based IOCs mentioned above, into a common VXI-based system. LANL [8] VXI modules were upgraded for faster pulse response at 2856 MHZ and are used with ANL's trigger timing module, constituting the central part of the system. Online SLED peak power measurements agree with power meter readings to within 2% after improvement of the envelope detector to optimize return loss. Rf phase is measured using two VXI modules, a downconverter, and a vector detector, plus conversion software which computes phase from the detected I and Q vectors. Measurements are repeatable to $\pm$0.1 degree after appropriate averaging.

Realtime screen readout and image analysis allow for visual phasing of each of the klystrons independently. Beam energy is measured, optimized, and/or set to a predefined value using fluorescent screen readouts in combination with dipole magnets. Computer algorithms keep the linac energy constant to within 0.1%; one regulates the rf phase to a constant value (to $\pm$2 degrees), and another [9] regulates the amplitude on a pulse-to-pulse basis by varying the trigger timing of the last SLED cavity in response to an energy measurement made with BPMs in the transfer line after the linac. The system's flexibility lends itself to development of new algorithms for equipment control and analysis.

Electron emittance measurements were easily made with the fluorescent screens in combination with triplets, but positron emittance has yet to be measured, since positrons and electrons are both present in the beam.

V. Conclusion

Construction of the APS linac has been completed, and comissioning is well underway. The 8-mA design goal for accelerated positron current has been met, and we are close (420 MeV) to meeting the the 450-MeV positron energy goal. Refinement of measurements and measurement techniques will continue for some time.

VI. Acknowledgements

We would like to sincerely acknowledge the efforts of Messrs B.E. Clifft, M. Douell, D. Fallin, C. Gold, J. Goral, J. Haumann, J.Hawkins, J. Hoyt, D. Jefferson, T. Jonasson, M. Lagessie, F. Onesto, S. Pasky, L. Peterson, V. Svirtun, and D. Yuen, without whose extraordinary efforts the linac would not have progressed as well and quickly as it did. Mr. A. Nassiri contributed significantly to the original linac design, and Ms. R. Lanham organized us, which was also very much needed. We appreciate the experience and technical guidance of Mr. G. Mavrogenes from the inception of this project.

VII. References

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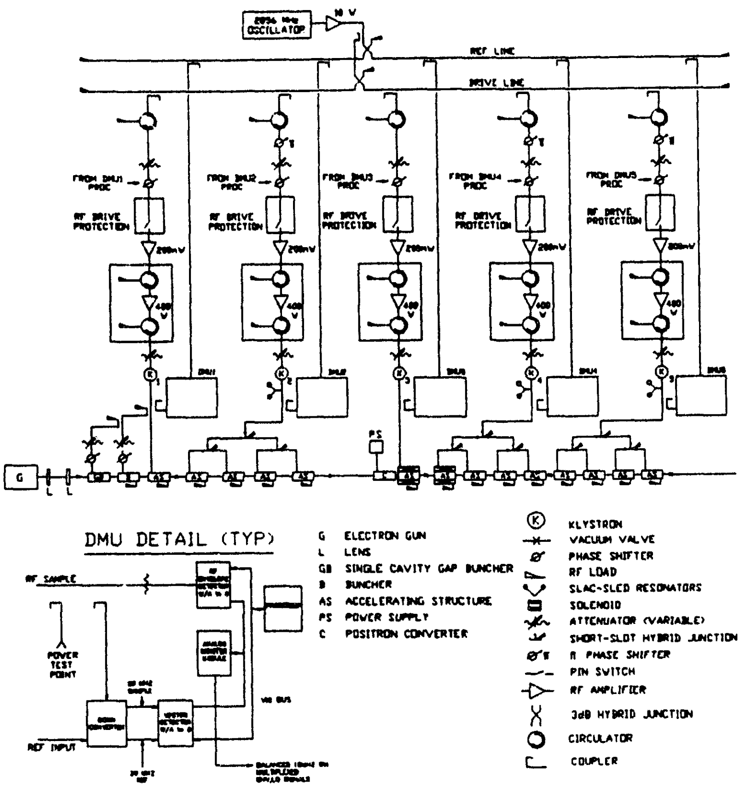

Figure 1
The Linac RF Circuit Diagram.

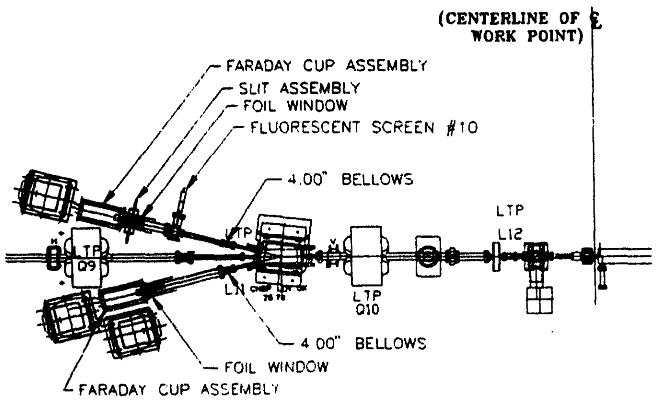

Figure 2
Diagnostic lines at the end of the linac allow for simple, optimization of positron current and energy.

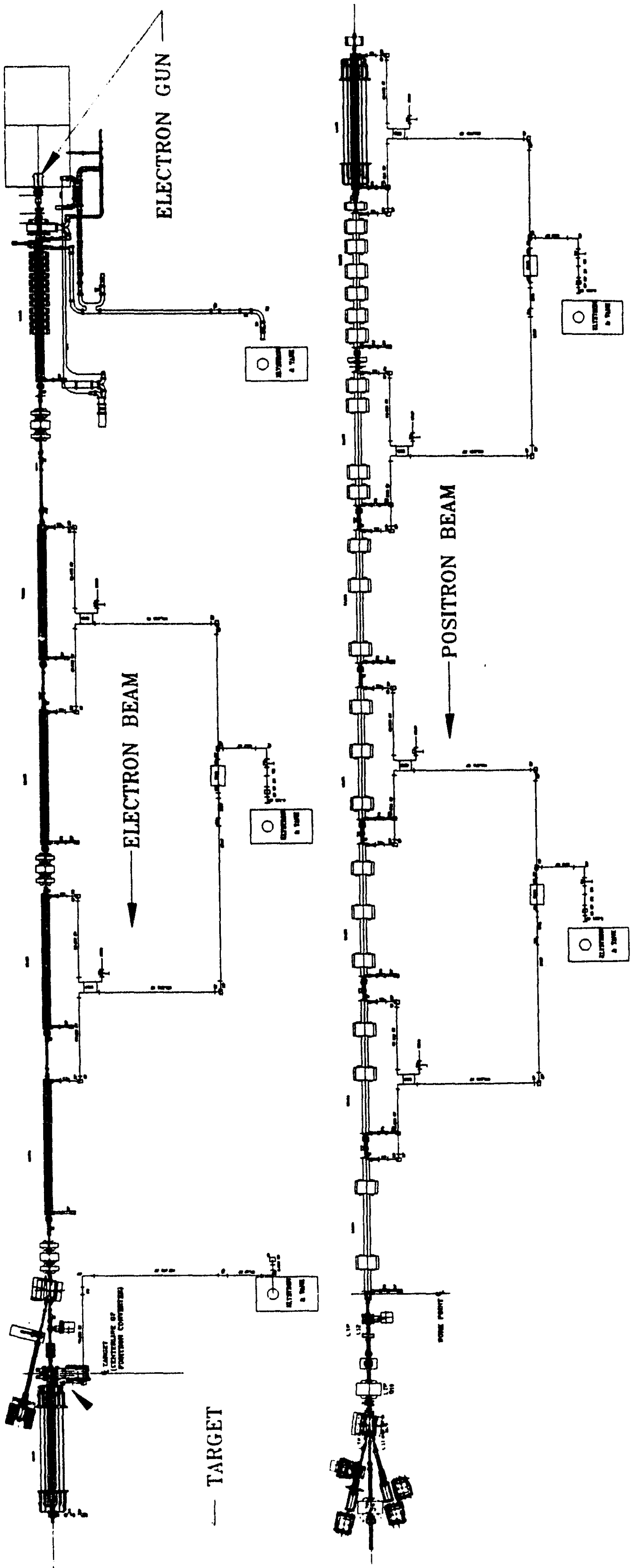

Figure 3
The Electron and Positron Linac Beamline.

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