CONF-860629--43

Received by OSTI

AUG 1 9 1986

ANL-HEP-CP--86-48

DE86 014540

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POSITRON INJECTION LINAC SYSTEM FOR THE ARGONNE LIGHT SOURCE*

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The Argonne 6 GeV Light Source will use positrons rather than electrons in order to avoid ion trapping of the residual gas. One of the primary requirements of the linac system is the capability to deliver relatively intense short bunches of positrons in the stationary buckets of the booster synchrotron without utilizing a positron accumulator ring. A linac system for accomplishing this task is described. It consists of a 200-MeV, high-current, electron linac and a 450-MeV positron linear accelerator with a DESY-type converter in between. The first accelerating section of the electron linac is a high field standing wave structure. The rest of the accelerating sections for both the electron and positron linacs are conventional disk-loaded T.W. guides using the SLAC-SLED pulse compression scheme.

Introduction

The general design of the linac and its beam parameters are set by the requirements of the system and the acceptance of the injector synchrotron.

The first section is a 200-MeV high-current linac. Seven 3-A electron pulses, each 16.5 nsec long, are accelerated in this section at a rate of 60 Hz. These electrons are focused to a 3-mm diameter spot at the 7-mm-thick tungsten positron-production target.

The electrons are longitudinally bunched to within 30° at 2.85 GHz and so the dominant cause of energy spread at the converter is transient beam loading. Since this is most pronounced in the injector, the section immediately after the buncher is a biperiodic standing wave structure with a 20 MeV/m accelerating field.

The positron pulses from the target are focused by a high field pulsed solenoid before injection into the positron linac for acceleration to 450 MeV. Assuming a 50% efficiency in the positron accelerating section, we expect the positron pulse to have a current of 10 mA, an energy of 450 ± 2.5 MeV and a 95 percentile emittance of 6.6 × 6.6 $(\text{mm}\cdot\text{mrad})^2$. The final e^+/e^- ratio is 0.0033. The option of accelerating a few milliamperes of electrons with energies up to 650 MeV by withdrawing the positron target is available.

The traveling-wave disc-loaded accelerating sections are of the SLAC type, with constant gradient and operating in the $2\pi/3$ mode. With an input power of 25 MW, each generates a 16.6 MeV/m accelerating field.

The 4-m-long region between the two linacs contains a spectrometer magnet, a focusing quadrupole triplet for the 200-MeV electrons, and the positron converter. The converter itself will absorb ~20% of the electron power of about 500 W. The resulting radiation levels are high enough to require local shielding.

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

The positron accelerating sections are exactly like the electron sections. To avoid arcing due to radiation, the first positron-accelerating section operates at a low field of ~7 MV/m and the following two sections operate at ~11.3 MV/m. The remaining four sections operate at a nominal 16.7 MeV/m. If it is required that the first section operate at an even lower field to avoid arcing, sufficient rf power is available to increase the fields in the rest of the sections to compensate. Care has been taken to keep the positron beam diameter smaller than 13 mm by a focusing system similar to those of DESY and LEP. This ensures that the positron beam is injected into the synchrotron with very high efficiency. Linac parameters are listed in Table I.

Table I
Nominal Linac Parameters

General	
Frequency	2.85 GHz
Klystron Power	35 MW
No. of Klystrons	4
No. of Sections/Traveling Wave	13
No. of Sections/Standing Wave	1
Repetition Rate	60 Hz
Beam Pulse Width	16.5 nsec
Electron Linac	
No. of Sections (incl. buncher)	5
Input Current	5.0 A
Input Energy	135 kV
Output Current	3.0 A
Output Energy	200 MeV
Output Emittance	1.2 π mm•mrad
Active Length	13 m
Physical Length	20 m
Converter	
Type	Tungsten
Thickness	7 mm
Conversion Efficiency e^+/e^- at Converter (for 200-MeV e^-)	0.0067
Positron Linac	
Input Current	20 mA
No. of TW Sections	10
Output Energy	450 MeV
Input Energy (mean)	8 MeV
Resolved Output Current	10 mA
Emittance	6.6 π mm•mrad
Energy Spread	±0.01
Active Length	27 m
Physical Length	32 m
Overall e^+/e^- Efficiency at 450 MeV	0.0033

Linac Injection System

The electron linac injection system produces a 5-MeV beam of 3.0-A current and 16.5-nsec pulse length at 60 Hz. The emittance is 3.0 π mm•mrad and energy spread is no more than ± 5%. It consists of a triode electron gun with a thermionic cathode similar to the one used at SLAC for the SLC.[1] A beam pulse ot ~5.0 A (the gun is capable of 10 A) and 16.5 nsec duration at 135 keV, β = 0.6 is generated by the gun. A set of two thin lenses focus the electrons into a reentrant cavity which acts as the first prebuncher and operates at the frequency of 2.85 GHz. After a drift distance of 60 cm, the electrons are further prebunched in a traveling-wave prebuncher which is one wavelength long at β = 0.6. They are then injected into the tapered (from β = 0.6 to β = 1.0) bunching section powered by ~5 MW of 2.85-GHz rf power to produce a tightly bunched electron beam for matched injection into the standing-wave section. This section has a high 20 MV/m accelerating field for low transient beam loading. The power and phase of all the injector components are adjustable through power splitters and phase shifters. The complete injector system, after the gun and including the standing-wave section, is in an axial magnetic field of ~0.1 T provided by a continuous Helmholtz coil system. Provisions are made so that the optimum magnetic profile is established and no external magnetic field penetrates the cathode of the electron gun. A separate 35 MW, non-SLED klystron is used for rf power with appropriate power division between the injector and the first accelerating section of the positron linac.

Accelerating Sections

The linac accelerating sections are disc-loaded waveguides operating in the $2\pi/3$ traveling-wave mode with constant field gradient. There are three traveling-wave sections in the electron linac and ten in the positron linac.

The design of the accelerating sections is similar to the SLAC design.[2] The basic performance criterion is an energy gain of 50 MeV per section with 20 MW input power and a field gradient of 16.6 MeV/m. The first traveling-wave section after the injector operates at 23 MV/m accelerating field with 20 MW input power for low transient beam loading. The first three positron-accelerating sections operate at low accelerating fields of 7 to 11 MV/m to avoid arcing due to radiation and the presence of electrons from the positron target.

With an attenuation of 0.57 nepers per section and 25 MW of input power, 13.0 MW is dissipated in the section and the rest in the terminating load. Each accelerating section has a separate cooling system that controls its temperature to $\pm$ 0.2°C, corresponding to a frequency shift of $\pm$ 0.5 MHz.

Each section consists of 86 elementary cells, including the two end couplers, with the iris diameter varying smoothly from 2.622 cm to 1.924 cm.

The copper accelerating structure is enclosed in a stainless steel cylindrical envelope and the pumping is achieved through 4-mm-diameter holes in the outer wall of the cavities. Two 100 ℓ/sec vac-ion pumps keep the pressure in the accelerating sections below 5×10^{-7} Torr with rf power on.

Klystron and Modulators

Since both linacs are working in the transient mode with a very short pulse of 16.5 nsec, we use the SLAC-SLED system.[3] Power is stored in the front part for the rf pulse for about 3 nsec in two high-Q cavities before a 180° phase reversal at the klystron input causes the energy in the storage cavities to be emptied into the accelerating structures. This increases the peak rf power by approximately a factor of three. These results have been duplicated at Laboratoire de l'Accélérateur Linéaire, Orsay, on a prototype of the SLED system using a 20-MW klystron and working into a resistive load.[4]

The rf power sources are 35 MW klystrons, such as the Thomson-CSF.TH2094.[5] Three klystron-modulator assemblies using the SLAC-SLED system are required to power the accelerating sections of the electron and positron linacs.

One additional klystron-modulator assembly without SLED is used to power the injector and the first accelerating section of the positron linac. Most of the rf power is directed to the injector through a power splitter and phase shifter.

The modulators are of the standard pulse-forming network line type with a tetrode charging switch in the input to regulate the input charge accurately.

RF Distribution

The output of the SLED resonant cavities (~100 MW) exceeds the arcing threshold of a transmission waveguide pressurized with SF_6; for that reason, the cavities and the transmission waveguide are under vacuum.

Copper rectangular waveguide (WR 284) is used for low rf losses. The estimated rf losses per accelerating section, including those of rf flanges, are ~0.4 db; hence, no water cooling is required.

The output from each SLED cavity (~100 MW) is divided and then subdivided into equal parts with magic T's as required (see Fig. 1). The phase of the rf power fed to the waveguides is controlled by high-power mechanical phase shifters.

Low-Level RF and Phase Control

The 3-GHz output of an ultrastable master oscillator is amplified to the 20-kW peak power level by a small booster klystron. A rigid coaxial line distributes this signal to the four klystrons through an electronic phase control circuit.

The phase adjustment of the accelerator is initially made by maximizing the energy of both linacs and at the same time minimizing the energy spread. From then on, the phases of the accelerating and bunching sections are compared to a reference cavity in the injector and the relative phase difference is kept constant by the control computer. A system measuring the phase difference between two cavities with an accuracy of $\pm$ 1° has been tested at Argonne and is incorporated into the system. The fixed energy, pulse width, and duty cycle for both electrons and positrons make the phase control system of the linac relatively simple.

Positron Production

For maximum utilization of the geometrical acceptance of the positron-accelerating sections, the 200-MeV electron beam impinging on the positron-conversion target is focused tightly to a spot size of no more than 3 mm in diameter. The energy spread of the incoming electrons is limited to $\pm$5% to avoid increasing the beam spot due to chromatic effects in the focusing system.

Following the DESY design,[6] the positrons are produced in a water-cooled retractable target that is made of two radiation lengths (7 mm) thick tungsten.

The energy distribution of positrons emerging from the target is inversely proportional to the positron energy, thus there are more lower-energy positrons than higher-energy positrons. The energy acceptance of the positron linac is set to accept the positron energy of 8 ± 1.5 MeV. Solid-angle acceptance of the system is defined by a pulsed solenoid placed immediately downstream of the target and positron-accelerating waveguide. The solenoid has a field strength of 1.5 T and an aperture equivalent to the acceptance solid angle of 0.15 steradians. Positrons from production angles up to 220 mrad in each transverse plane are captured in the acceptance aperture.

The accepted positron emittance is ε = 330 mm·mrad (220 mrad × 1.5 mm) in each transverse plane, where the beam size of 1.5 mm radius is used. The positron yield per an accident electron of 200 MeV accepted by the system is 0.00675. This yield is equivalent to injection of 20 mA positron pulse current into the positron linac. The positron linac loss is assumed to be 50%. The final positron to incident electron ratio, including transmission losses, is e^+/e^- = 0.0033. This results in a 10-mA positron current at 450 MeV.

The 450-MeV positron beam has an emittance of 6.6 mm·mrad in each transverse plane, and an energy spread $\Delta E/E$ = ± 0.006. An emittance dilution of 12% is assumed.

Focusing

The electron beam leaving the gun is focused by two short solenoid lenses. From there on, and all along the injector, the beam is radially focused by an axial magnetic field produced by a Helmholtz coil system of 0.1 T field and appropriate profile.

Downstream from the Helmholtz coil system, the beam is focused by three quadrupole triplets placed between accelerating sections to give the required beam spot on the positron target with a corresponding emittance of 6 mm·mrad (at 200 MeV) for 90% of the electrons.

After the target and the short pulsed solenoid (~1.5 T), the positrons are focused by a solenoid with a 0.4 T magnetic field, which is wound around the first two positron-accelerating sections. There is a limiting aperture of 1.5 cm at the entrance of the first positron-accelerating section.

Subsequent focusing is similar to that at LEP[3] and consists of a matching section of quadrupoles followed by a FODO system. The spacing of the quadrupoles increases with energy.

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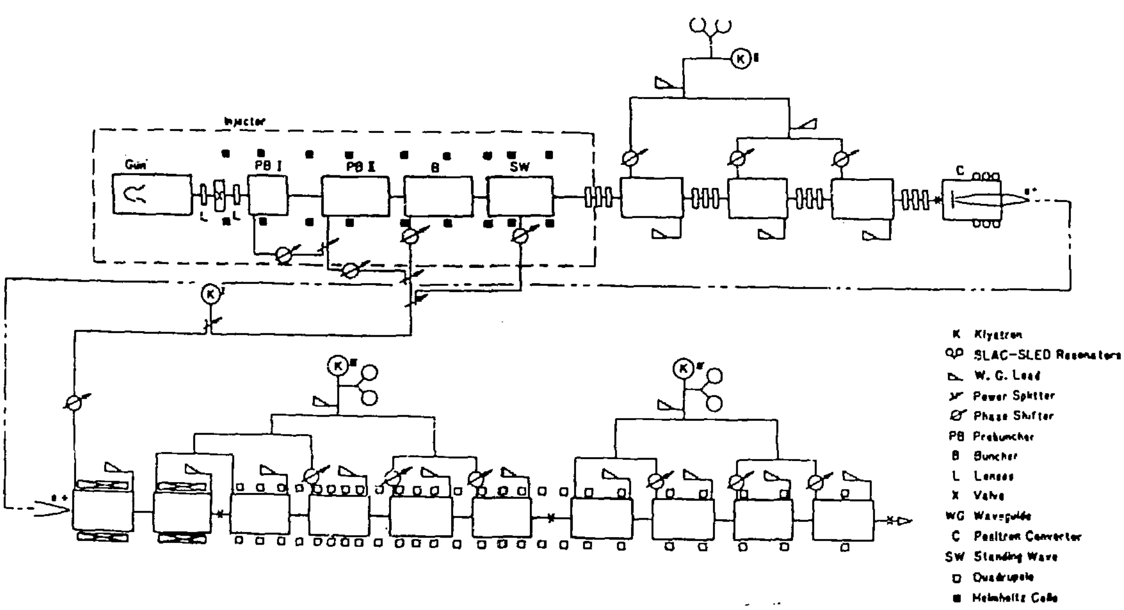

Fig. 1. Schematic diagram of the electron and positron linacs showing the rf power distribution.

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