

A PROPOSAL FOR A HIGH CURRENT, HIGH DUTY FACTOR ELECTRON ACCELERATOR*

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Abstract

A linac-Pulse-Stretcher-Ring has been proposed for the generation of high duty factor, high current electron beams in a nominal energy range of 0.5 to 2.0 GeV.¹ A low duty factor linac beam is injected into a storage ring from which it is slowly extracted to yield a high duty factor. The linac beam is composed of 1.2 μ s current pulses containing 240 nC/pulse with a repetition rate of 1 kHz. Each pulse is injected vertically during a single turn into the pulse stretcher ring, a 377.89 m oval with a magnetic radius of 29 m. Excitation of an n/3 betatron resonance in the horizontal plane is used in conjunction with electric and magnetic septa for extraction. Typical extracted beam parameters are: horizontal emittance $\leq 0.3\pi$ mm-mrad, vertical emittance $\leq 0.1\pi$ mm-mrad, and an energy spread $\leq 0.1\%$. The extracted beam has a maximum average current of 240 μ A, a duty factor $> 90\%$, and may be polarized. Beam characteristics, design parameters, and facility layout are discussed.

Introduction

Recent analyses² of the future of nuclear science have emphasized the need for the development of a new, high duty factor electron accelerator. Great interest within the physics' community in the role of subnuclear degrees of freedom in the description of nuclei dictates that the attainable energy of this machine be in the multiple-GeV range. All proposed nuclear studies^{1,3} in this regime may be accomplished utilizing electron beams with an emittance of 0.2π mm-mrad in at least one transverse plane, a momentum spread of 0.1%, and a duty factor in excess of 50%.

Historically, there has been a desire to increase the energy of accelerators after they are constructed. Therefore, an accelerator must be easily upgradeable in energy if it is to be cost effective. We have considered several alternative designs and have found the Linac-Pulse-Stretcher-Ring (LPSR) to be the best machine choice given the required beam parameters and the desire for future beam energy upgrade. The basic concept of the LPSR is to transform the time structure of a pulsed linac to a high duty factor by filling a pulse stretcher ring (PSR) with a linac pulse and extracting that current from the PSR over the time period between linac pulses, as shown in Fig. 1. While the idea of a LPSR is not new,⁴ the particular design discussed below combines state-of-the-art technologies to achieve electron beams of quality comparable to those expected for alternative development projects.⁵

The accelerator design objectives are listed in Table I and the proposed facility is shown in Fig. 2. Linac pulses, 1.2 μ s in length containing 240 nC, are injected vertically into the PSR at point I using a single-turn scheme at a repetition rate of 1 kHz. The injected current is extracted horizontally from the PSR at points E1 and E2 during the 1 millisecond between successive linac pulses. The high duty factor beam extracted from point E1 can be divided in the Beam Switch Yard (BSY) into three separate beams of varying intensity, each of which can then be delivered to a separate end station (A,B, or C). A second extraction point in the PSR, E2, provides a low intensity beam to the tagged photon facility. The BSY has been designed to deliver polarized electrons to any of the primary end stations (A,B, or C). As well, interlaced beams of

differing energy and polarization may be transported directly from the linac to these end stations.

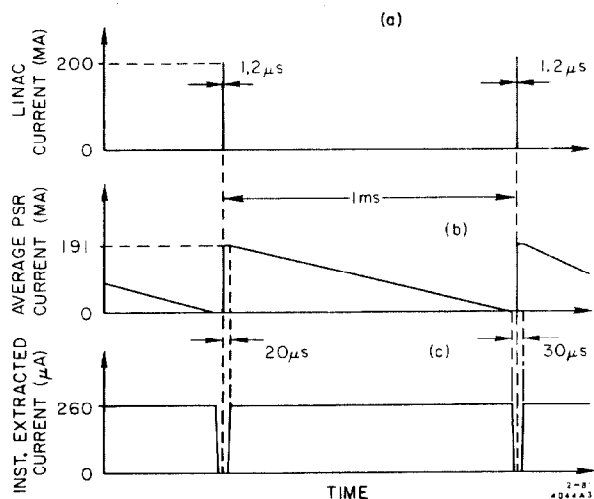


Fig. 1. Linac-PSR Time Structure: (a) 200 mA, 1.2 μ s linac beam pulses are injected into the PSR every 1.0 ms. (b) The average stored current in the ring is constant for approximately 20 μ s after injection. Peak stored current is reduced from the instantaneous injected current by a factor of 0.95 due to the difference in the ring circumference and the linac pulse length. (c) Current extracted from the ring rises to steady-state about 20 μ s after injection, falling to zero about 10 μ s before the next injection. Every 1.26 μ s there is a 60 ns gap in the extracted beam due to the disparity in the linac pulse length and the PSR circumference.

TABLE I
Accelerator Design Objectives

Energy Range Initially	0.5 GeV to 2.0 GeV
Ultimately	to 4.0 GeV
Energy Variability	Continuously from 0.5 GeV
Energy Spread	$dE/E \leq 10^{-3}$
Duty Factor	DF $> 75\%$
Number of Beams	3 to standard end stations 1 to tagged photon facility
I (average)	$> 200 \mu$ A
I (per beam)	$\leq 100 \mu$ A to each end station $\leq 1 \mu$ A to tagged photon facility
Emittance	$\leq 0.1\pi$ mm-mr in vertical plane $\leq 0.3\pi$ mm-mr in horizontal plane
Polarization	Longitudinal or transverse at all energies

* Work supported by the Department of Energy, contract DE-AS-5-80ER10633.

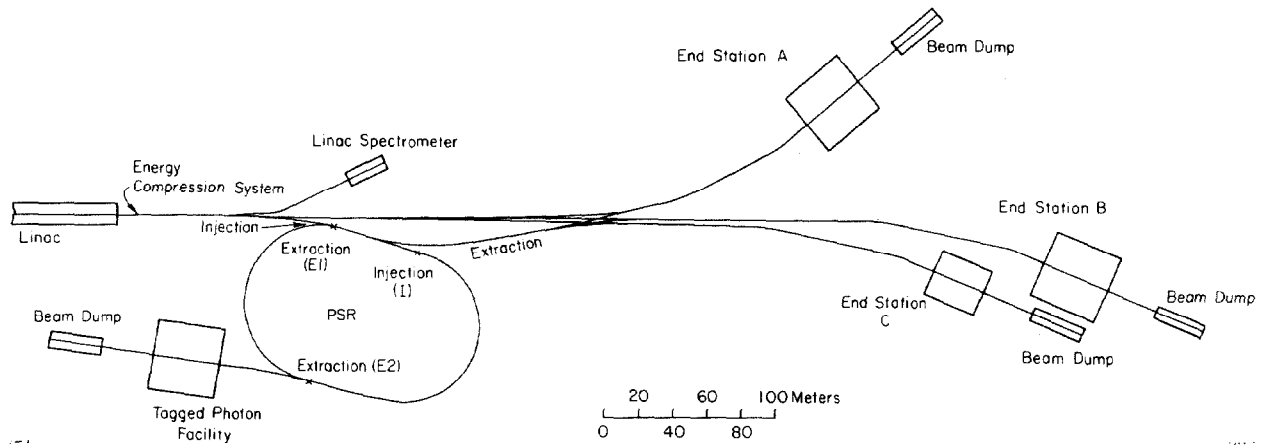


Fig. 2. Proposed Accelerator Facility.

PSR

The global PSR parameters were largely determined by the decisions (1) to use single turn injection; (2) to use resonant extraction; (3) to allow a maximum energy spread of 2% in the linac beam; and (4) to use 2 GeV as the nominal design energy. The single turn injection requirement was imposed to allow a lower emittance in the extracted beam than would be possible if multiturn injection were used. Extraction is based on an $n/3$ horizontal betatron resonance. For energies ≤ 2 GeV, monochromatic extraction is used wherein the electrons are forced onto the extraction resonance by the energy loss due to synchrotron radiation coupled to a non-zero chromaticity. Wiggler magnets are used to enhance the rate of energy loss to synchrotron radiation for electron energies significantly below 2 GeV. For energies above 2 GeV, an achromatic method is employed in which a system of ramped quadrupoles is utilized to move the tune onto the extraction resonance while a 476 MHz RF system is used to compensate for the synchrotron radiation energy loss. Two GeV was chosen as the nominal energy based on a compromise between ease of low energy operation and ease of expansion to higher energies.

An analysis for this type of accelerator performed by G. A. Loew⁶ demonstrates that a cost minimum exists for a PSR magnetic bend radius of approximately 30 m. This corresponds to a circumference of about 370 m, which in turn implies a linac pulse length of ~ 1.2 μ s. The linac repetition rate of 1 kHz is determined by the amount of time required for the most energetic particles in the beam to lose 2% of their energy. The resulting lattice design shown in Fig. 3 has a magnetic bend radius of 29 m and a circumference of 377.89 m. Also noted in Fig. 3 are the locations of the wiggler magnets (W) and injection (I) and extraction (E1, E2) points. The bending arcs are composed of two types of cells, 12 repetitive cells of an achromat⁷ with a tune advance of 0.25 in each plane across each cell and "missing magnet" dispersion matching cells.

Linac pulses are injected on axis in the vertical plane and slightly off axis in the horizontal plane. As illustrated in Fig. 4, the injection elements consist of a magnetic septum, an electric septum, and two pulsed magnets. The primary injection kicker (PIK) following quadrupole QI3 vertically deflects the beam a final 0.13° to bring it on axis. The rise/fall time of the PIK is about 80 ns.⁸ When the tail of the pulse has passed the PIK the field begins to fall but will not reach zero before the head of the pulse returns. Electrons at the head of the pulse will, therefore, be deflected a second time by the PIK. In order that the beam be kept vertically on axis, a secondary kicker is placed upstream between quadrupoles

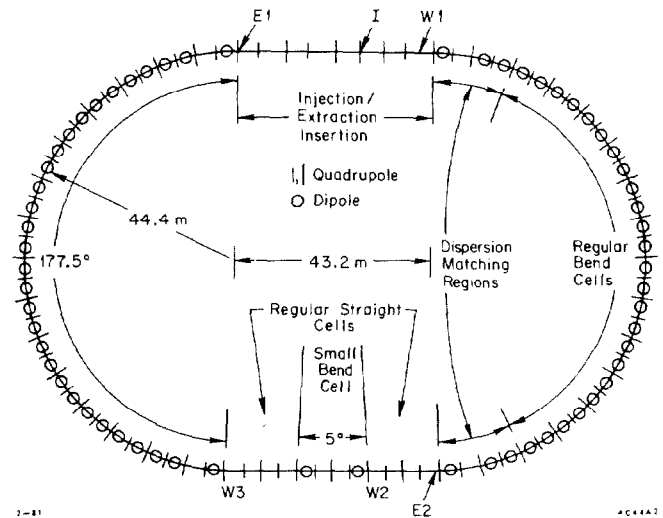


Fig. 3. Pulse Stretcher Lattice.

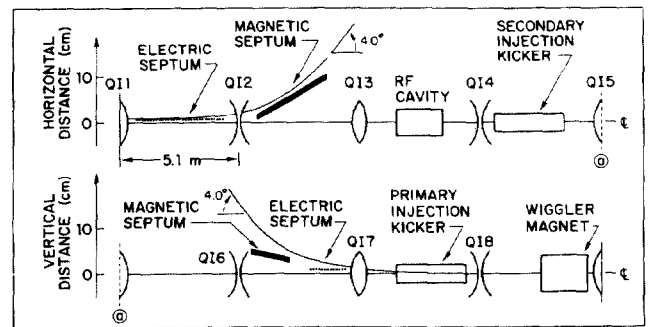


Fig. 4. Injection/Extraction region of the Pulse Stretcher Ring.

QI4 and QI5. The strength of this secondary injection kicker is matched to that of the PIK to provide a resultant null beam deflection. The electric and magnetic septa used in extraction are indicated in Fig. 4.

Transversely polarized electrons can be injected into and extracted from the PSR. Longitudinal polarization at the target will be obtained by means of a polarization rotation chicane consisting of two superconducting solenoids on either side of a 16 degree

achromatic bend followed by a final 32° achromatic bend in either direction. This system will allow almost 100% rotation efficiency over the energy range of 0.5 to 4.0 GeV to permit future energy upgrade.

Linac

A linear accelerator (linac) has been designed to generate electron beams which match the admittance properties of the PSR. Linac beams are composed of 1.2 μ s current pulses containing 240 nC/pulse (200 mA peak current) with a maximum repetition rate of 1 kHz and a mean energy that is variable from 0.5 GeV to >2.0 GeV. These beams exhibit a transverse emittance of $5\pi \times 10^{-3}$ (MeV/c)/cm, are capable of being polarized, and have an adjustable energy spread. The linac can deliver beam pulses either to the PSR or directly to the end stations. Multiple beams of different energies, peak currents, pulse widths, and repetition rates may be interlaced such that experimenters may specify desired beam characteristics independently of each other.

Figure 5 outlines the general plan of the linac. Electrons are generated, polarized if desired, bunched at a frequency of 476 MHz, and preaccelerated to 20 MeV in the injector region. The beam pulses are accelerated to the chosen terminal energy in the accelerator portion

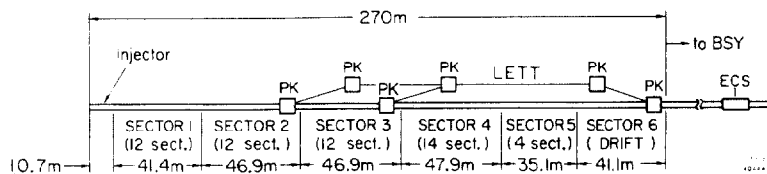


Fig. 5. Layout of linac, PK = Pulsed Dipoles, LETT = Low Energy Transport Tube, ECS = Energy Compression System.

which consists of a series of SLAC-type constant-gradient, traveling-wave accelerator sections. Low energy beams are extracted from the accelerator after sectors 2 and 3 to reduce the effect of transient beam loading on the beam energy spectrum. An energy compression system (ECS) designed to tailor the beam spectrum is located downstream of the linac in the BSY area. Pulsed, 40 MW, 2856 MHz klystrons are used to provide RF power to the accelerator, each klystron driving 2 sections. A design encompassing 54 sections and 27 klystrons has been selected to allow 2 GeV operation at 200 mA/pulse with 92% utilization of available klystrons. Energy upgrade will be accomplished by filling sectors 5 and 6 with accelerating sections and increasing the RF power level to 40 MW per section. This configuration of 70 powered sections will be able to deliver a 200 μ A, 4.2 GeV beam.

Energy Compression System

An energy compression system (ECS) is required to tailor the energy spectrum of the linac beam pulse. Because of the large peak currents desired from the linac, transient beam loading (TBL) in the accelerating cavities will broaden the beam energy spectrum in comparison to that for currents at which beam loading is negligible. The effect of TBL on the energy spectrum may be reduced by selectively varying the triggering of klystrons with respect to the time at which the beam traverses a particular accelerating waveguide. However, the spectrum resulting from such a procedure will still exhibit a temporally dependent energy ripple. Injection into the PSR of a current pulse with such a spectrum will result in an extracted beam with a current amplitude ripple.

The ECS, located at the end of the linac, is used as a ripple suppressor for linac pulses sent to the ring. At energies above 2 GeV when achromatic extraction is used and for pulses sent directly to the end stations, the ECS may be used as the more familiar energy compressor by suitable variation of the ECS operating parameters. Overall, the ECS is very similar to those extant.⁹

Experimental Facilities

As currently envisaged, there will exist as many as three primary end stations (A, B, and C) and a tagged photon facility. Preliminary plans include the installation of a high resolution spectrometer (HRS) in end station A. This spectrometer will have a momentum resolution of about 5×10^{-5} , a maximum momentum acceptance of 1.5 GeV/c, and be of the dispersion matching type. A design similar to the HRS at the Los Alamos Meson Facility is being considered. End station B is the planned site of a spectrometer pair to be used in coincidence measurements or similar experimental circumstances where a momentum resolution of 0.1%, a momentum acceptance of 4 GeV/c, and a solid angle of 10 to 20 msr are required. Because of the high momentum and solid angle demands, the utilization of superconducting elements is being studied as a solution. The tagged photon area will, in addition to standard tagging equipment,¹⁰ contain transport elements to take the virtually undegraded electron beam to a test beam area.

Conclusion

A Linac-Pulse-Stretcher-Ring has been proposed for the generation of a high duty factor, high current electron beams. The linac, a standard pulsed, traveling-wave accelerator, injects beam vertically during a single turn into the PSR. High duty factor beam, extracted from the PSR by the excitation of an $n/3$ betatron resonance in the horizontal plane, may be transported to any of four proposed end station facilities. The design is based on state-of-the-art technologies which provides a measure of confidence in the cost analysis, in the predicted construction schedule, and in the realization of the required beam characteristics.

Acknowledgements

The authors would like to take this opportunity to thank all those people at SLAC without whom this project would never have gone beyond idle discussion.

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