SLAC-PUB-6852
May, 1995

The NLC Positron Source*

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Abstract

A baseline design for the NLC positron source based on the existing SLC positron system is described. The proposed NLC source consists of a dedicated S-band electron accelerator, a conventional positron production and capture system utilizing a high-Z target and an adiabatic matching device, and an L-band positron linac. The invariant transverse acceptance of the capture system is 0.06 m·rad, ensuring an adequate positron beam intensity for the NLC.

Contributed to the 1995 Particle Accelerator Conference and International Conference on High-Energy Accelerators

Dallas, Texas, May 1–5, 1995

* Work supported by Department of Energy contract DE-AC03-76SF00515.

I. INTRODUCTION

The Next Linear Collider (NLC) proposed by SLAC [1] uses a pulsed multi-bunch positron beam with an intensity requirement that is over an order of magnitude greater than the SLC design limit of 7×10^{10} positrons per beam pulse. This presents the primary challenge in designing the NLC positron source since a simple scale up of the SLC positron source would not be feasible due to the excessively high beam energy that the target would have to withstand. Thus, a significant improvement in the positron capture efficiency is essential in realizing the NLC source [2]. In this paper we present a baseline design that is reasonably conservative and uses only existing technologies. We use the SLC positron source [3] as the basis for our design, as its design principles have been well tested in many years of SLC operation, and make necessary changes to accommodate the significantly higher beam intensity requirement for the NLC. Table 1 lists the important parameters for the NLC positron source, along with the SLC positron source parameters for comparison.

As in the SLC, the conventional technique of producing positrons by bombardment of a conversion target with high energy electrons will be used. The proposed NLC positron source consists of three systems: an electron accelerator complete with a thermionic gun, an RF bunching system and a linac, a positron production target and a capture system, and a positron linac. In what follows the designs for these systems that meet the NLC-II specifications will be discussed.

Table 1. NLC and SLC Positron Source Parameters

Parameters	SLC 94	NLC-II
Electron Drive Beam		
Electron Energy (GeV)	30.00	6.22
No. of bunches per pulse	1	75
Bunch Intensity	3.5×10^{10}	1.5×10^{10}
Pulse Intensity	3.5×10^{10}	113×10^{10}
Beam Pulse Energy (J)	168	1120
Repetition Rate (Hz)	120	120
Beam Power (kW)	20.2	134
Beam σ on target (mm)	0.8	1.6
Pulse Energy Density ρ (GeV/mm^2)	5.22×10^{11}	8.70×10^{11}
Positron Collection		
Wall Emittance (m·rad)	0.01	0.06
Energy Cut (MeV)	20	20
Longitudinal Cut (psec)	15	60
Yield (No. of e^+ s per e^-)	2.4	2.1
Bunch Intensity	8.4×10^{10}	3.2×10^{10}
Pulse Intensity	8.4×10^{10}	236×10^{10}

II. ELECTRON ACCELERATOR

A thermionic gun and an RF bunching system incorporating two subharmonic bunchers and a S-band buncher similar to those on the SLC injector are used to generate an electron beam with the desired NLC time structure. Then, the electron beam is accelerated in an S-band (2856 MHz) linac with damped-detuned structures [4] to an appropriate energy (3.11 GeV for NLC-I or 6.22 GeV for NLC-II) for positron production. Beam loading compensation in the accelerator will be accomplished using pairs of structures operated at 1 MHz above and below the main RF frequency, i.e., the so-called Δf approach.

III. POSITRON PRODUCTION AND CAPTURE

A. Positron Production Target

Since each electron beam pulse deposits a large amount of energy in the target, the target must be moving with respect to the beam position to avoid successive beam pulses hitting the same spot on the target which would damage the target. For the NLC positron source, we propose a rotating target design. While this design minimizes possible intensity modulation of the captured poisitron beam due to target motion, sealing of the target chamber needs special consideration.

For a moving target, target failure may still occur if the energy density of the drive beam is so high such that excessive thermal stress is created due to instantaneous, localized beam heating from the impact of a single beam pulse. By virtue of its good thermal and mechanical properties and its high Z characteristic, $W_{75}Re_{25}$ is chosen to be the target material. Laboratory tests at SLAC [5] established an upper limit on the pulse energy density of the impinging electron beam at

$$\rho_{max} = N_- E_- /(\pi\sigma^2) = 2\times10^{12}\ \mathrm{GeV/mm}^2,$$

where N_- is the number of electrons per pulse, E_- the energy of the incident electrons, and σ the rms radius of the electron beam at the target. Thus, we choose the electron beam size at the target to be 1.6 mm, sufficient to keep the energy density comfortably at 8.70×10^{11} GeV/mm^2.

Considerations of the drive beam power and target cooling lead to a ring-shaped target design with an outer and inner diameter of 20 cm and 19 cm, respectively. A rotating frequency of 2 Hz should be adequate to allow for sufficient separation between successive pulse impacts on the target. Cooling tubes will be located in a silver casting in close contact with the inner target ring surface to maximize the rate of heat conduction from the target to the cooling tube walls. Cooling water flowing at a rate of 1.3 -

2.0 l/s will keep the steady-state temperature of the target at a safe level so as not to degrade the material properties.

One of the key engineering issues is to vacuum seal the rotating target shaft which must pass from atmosphere into the target vacuum chamber where the vacuum is on the order of 1×10^{-7} Torr. Our proposal is to use a combination of radiation resistant conductance-limiting seals and several stages of differential vacuum pumping along the length of the drive shaft. These seals rely on tight clearance (<10 μm) between the shaft and seal surfaces and long path length (>> 1 cm) to limit vacuum conductance through them. A conceptual design of the NLC positron target system shown in Fig. 1 calls for three stages of differential pumping employing oil-free scroll and turbo pumps, while two ion pumps maintain the vacuum in the target chamber. The drive shaft is supported by two sets of bearings, one inside the target vacuum chamber and the other in atmosphere. Cooling water is coupled to tubings embedded in the shaft via a mating unit surrounding the shaft employing radiation-resistant seals.

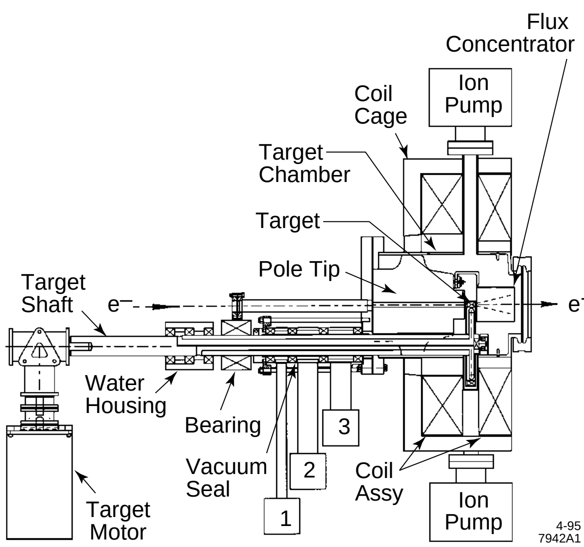

Figure 1: A conceptual design of the NLC target system with three stages of differential pumping.

B. Positron Capture

The positrons emerging from the converter target have small spatial and temporal but large angular and energy distributions. Therefore, the use of a large bandwidth phase-space matching device, such as a pulsed flux concentrator similar to the one used on the SLC positron source [3], is essential to allow for efficient positron capture into the accelerator section embedded in a long solenoid magnet. In this design, the maximum field requirement from the flux concentrator is 5.8 T along its axis. The minimum radius of its internal cone needs to be increased to 4.5 mm from 3.5 mm for the SLC version to accommodate the slightly larger radial extent of the emerging positron beam as a result of the increased drive beam size. As for the SLC, the DC solenoid that surrounds the capture accelerator is required to produce a 0.5 T field.

In order to maximize the transverse as well as the longitudinal phase space acceptances, we propose to use an L-band (1428 MHz) capture accelerator as opposed to the S-band design for the SLC positron source. This L-band design allows the accelerator structures to have a 20 mm radius aperture. Embedded in the 0.5 T uniform longitudinal field, the capture accelerator has an invariant transverse acceptance of 0.06 m·rad, with a headroom of 2 mm to allow for possible steering and alignment errors. The total length of the L-band capture accelerator surrounded by the DC solenoid is 12 m, and the loaded accelerating gradient is 20 MV/m.

C. Positron Yield Calculation

The positron yield from the target has been calculated using the EGS program [6] for 6.22 GeV electrons impacting a $W_{75}Re_{25}$ target of thicknesses ranging from 4 to 6 radiation lengths (1 RL ≅ 3.43 mm). By considering both the yield and the amount of beam energy deposited in the target, the optimal target thickness is found to be about 4 RL. At this thickness, the target yield defined as the number of positrons produced per incident electron is 12.5, and about 14% of the electron beam energy is deposited in the target.

The particle rays obtained from the EGS simulation have been traced through the flux concentrator and the capture accelerator up to the nominal 250 MeV end point using the ETRANS program [7] – a ray tracing program developed at SLAC that integrates particle trajectories through static magnetic and RF fields while ignoring the effect of space charge and wake fields. By varying the RF phase of the accelerating field, the best positron yield at the end of the capture accelerator is found to be 2.1 within an energy window of 20 MeV and a longitudinal window of 60 psec. Thus, with 1.5×10^{10} electron/bunch in the drive beam, the captured positron beam would have a bunch intensity of 3.2×10^{10}, which is nearly three times the required intensity of 1.1×10^{10} at the interaction point for NLC-II. We feel that such a safety margin should be adequate to offset any unaccounted for beam loss in the capture section due to space charge and wake field effects and additional beam losses in downstream accelerator components.

D. Maintenance and Reliability Considerations

Due to the high radiation activity in the areas around the target in particular and the low energy electron beam dump as well, access to these radiation-hot areas during a physics run must wait until the radiation activity drops to an acceptable level. As such cooling periods can be up to a month long, any maintenance work in these areas means a long down time for the accelerator. A logical approach to increase the efficiency of the positron source is to build two identical positron production and capture systems adequately shielded from each other such that access to one system is permitted while the other is running. A schematic layout of the NLC positron source with two side-by-side positron vaults is shown in Fig. 2. Calculations

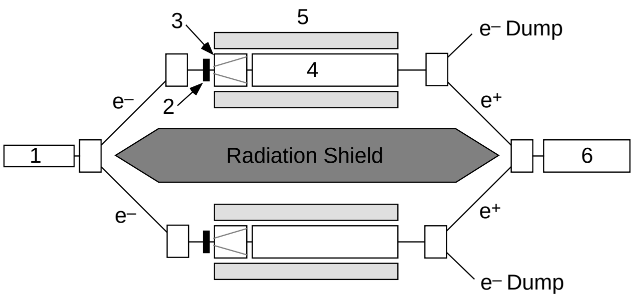

Figure 2: Schematic layout of the NLC positron source with two side-by-side positron production and capture systems: 1 – electron accelerator, 2 – positron target, 3 – flux concentrator, 4 – L-band capture accelerator, 5 – tapered-field solenoid and uniform-field solenoid, 6 – 1.8 GeV positron linac.

show that a 6-m thick concrete wall is sufficient to shield one vault from the other. The input electron beam can be directed to either system via bending magents that are isochronous and linearly achromatic. Likewise, the 250 MeV positron beam after the capture accelerator from either system is directed into a common 1.8 GeV L-band linac. The first bending magnet following the capture accelerator also serves to separate the captured electrons, which are co-produced along with the positrons from the electromagnetic shower cascade in the target, from the positron beam. The two-vault design should greatly improve the serviceability of the positron source and, therefore, boosts its operation efficiency.

IV. POSITRON LINAC

The optics for the 1.8 GeV L-band positron linac is a strong focusing FODO lattice consisting of large aperture quadrupole magnets. The phase advance of the lattice is chosen to be 60˚/cell, while the beta function is chosen to scale as $E^{0.5}$ along the linac. Coupled with a Gaussian detuning of 10% total fractional frequency spread in the accelerating structures, there should be negligible wake-field induced multi-bunch beam blow-up. As in the S-band electron drive linac, the Δf approach will be used for beam loading compensation.

V. ACKNOWLEDGMENTS

We thank P. Emma, G. Gross, W. Nelson, K. Thompson, J. Turner, T. Umemoto, and V. Vylet for their important contribution to the design of the NLC positron source.

VI. REFERENCES

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