A SIMULATION STUDY OF THE JLC POSITRON SOURCE

T. Kamitani*, Y. Ohnishi, KEK, Tsukuba, Ibaraki, Japan
S. Kashiwagi, Waseda University, Tokyo, Japan

Abstract

This paper describes a parameter optimization of the JLC positron source design by detailed particle tracking simulations. The design parameters are modified from those of the previous JLC design study [1], considering the energy-density limit of the converter-target damage and the recent change in the specifications, especially the twice increase of a charge intensity of a beam pulse [2]. It is shown that a multiple target system to share the deposition energy is inevitable and at least three targets are necessary to yield sufficient positrons within the energy-density limit.

INTRODUCTION

The design of the JLC positron source [1][2] is based on a conventional scheme of positron production using high-Z material target irradiated by a high-energy electron beam as shown in Fig.1. A combination of a pulsed solenoid (flux concentrator) and DC solenoids is used for the transverse phase space matching. The solenoid field is varied slowly from 7.0 T to 0.5 T to achieve an adiabatic matching so as to have a wide energy acceptance. A long flat solenoidal field of 0.5 T extends in the several meters to cover the accelerating structures in the capture section. Only the positrons which can pass through the aperture of the accelerating structure are captured and accelerated. L-band accelerating structures are used here, because it has large aperture (20 mm in radius) and long RF wave length (210 mm), thus having large acceptance both in transverse and longitudinal phase space. The positrons are accelerated up to 180 MeV with the L-band structures in the solenoid focusing region and are transferred to the quadrupole focusing system. In the downstream, the positrons are accelerated by a S-band linac up to 1.98 GeV for injection to the pre-damping ring (PDR).

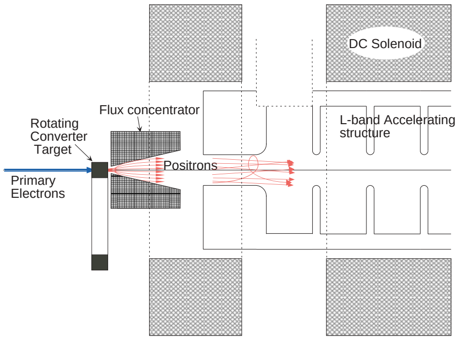

Figure 1: JLC positron source

An intensity of 14.4×10^{11} positrons/pulse, which is equivalent to that of electrons, is require in the present JLC design. It was increased more than twice, compared with the previous design (6.0×10^{11} particles/pulse) [1]. A beam pulse has a structure like a train of 192 bunches in 1.4 nsec interval, each having 0.75×10^{10} positrons. A repetition rate of the beam pulse is 150 Hz. A primary electron beam, whose intensity is 19.2×10^{11} electrons/pulse, is accelerated up to 10 GeV at the converter target to produce positrons. A performance of the positron source is evaluated by the positron yield which is defined by a ratio of the positron intensity to that of the primary electrons. Assuming a loss of the positron beam from the PDR to the interaction point is negligible, the positron yield is estimated by calculating a conversion ratio from electrons to positrons in the converter target and a fraction of positrons which survive during a transmission from the capture section to the PDR injection. A design goal of the positron yield is $Ne^+/Ne^- = 0.75$.

ENERGY-DENSITY ESTIMATION

Tungsten-Rhenium alloy has been chosen as a converter-target, because of the high melting point and the high tensile strength. The thickness of the target was determined to be 21 mm (6.0 radiation lengths) for the optimum positron yield with the 10-GeV primary electron beam. A rotating structure is used so that each beam pulse hits a different part of the target to prevent concentrated heat deposition. Nevertheless, the energy deposition by a single beam pulse may exceed the threshold for target damage due to fatigue. From analysis of the cracked SLC positron source target, the threshold for damage is estimated to occur when the local density of the energy deposition is 35 J/g, as reported in the NLC positron source design [3]. This limit is used as a reference in the design of the JLC positron target. Increasing the transverse size of the primary beam helps reduce the energy density in the target. Examples of the energy-density in the target are shown in Fig.2, for two cases of the incident beam sizes of 2.0 and 3.0 mm. The densities grow as the beam go deeper in the target and the peaks are at the exit. By increasing the beam size from 2.0 to 3.0 mm, the peak energy density becomes almost half. It is because the energy deposition is smeared out in wider region as shown in the contour plots in Fig.2. The energy densities in the plots are for the case of the beam intensity which is one-third of the JLC specification.

Though increasing the beam size reduces the energy density, it also reduces the positron yield, because larger fraction of the produced positrons go out of the acceptance aperture. As shown later, if the incident beam size is suf-

---

[*] takuya.kamitani@kek.jp

0-7803-7739-9 ©2003 IEEE

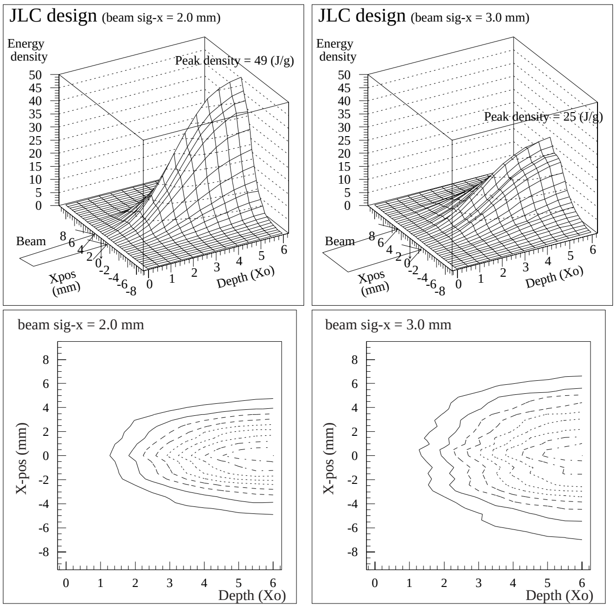

Figure 2: Energy density distribution

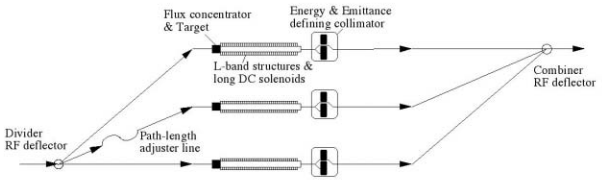

Figure 3: Multiple target system

ficiently large concerning the energy density, the positron yield is far below the requirement. To keep the density well below the threshold with sufficient positron yield, multiple target system is used for the energy deposition to be shared as proposed for the NLC [3]. A candidate multiple target system for the JLC is shown in Fig.3. To divide the bunches in a beam pulse into three, an RF deflector cavity whose oscillation is synchronized to every third bunch is used. The three groups of the sparse bunches go towards the different target. Each target is followed by a positron capture section and a collimator to define energy and emittance. The three groups of the produced positrons are then merged with another RF deflector cavity. To see the effect of using the multiple targets, the peak energy density and its dependence upon the incident beam size is evaluated for the case of one to four targets. The result is shown in Fig.4. The EGS4 shower simulation code [4] was used to calculate the energy depositions in small volumes in the target. The acceptable minimum beam sizes to clear the density limit are 4.8, 3.2, 2.5, 2.1 mm for single, 2, 3, 4 target systems, respectively. By using multiple target, the acceptable beam size become smaller.

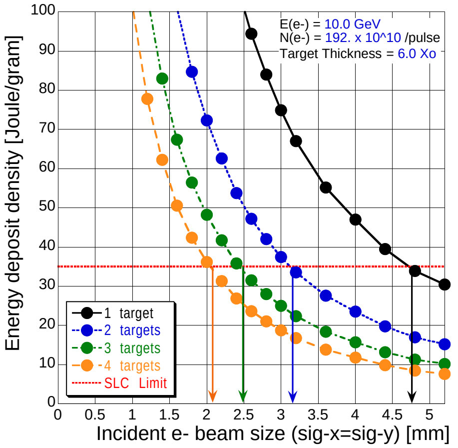

Figure 4: Energy density as a function of beam size

POSITRON YIELD ESTIMATION

In order to estimate the positron yield for each case of the multiple target systems, detailed particle tracking simulations were performed.

As a first step, positron production in the target was simulated using the EGS4 code. Approximately, twenty-thousand positrons were generated in the 21-mm thick tungsten-rhenium target from a thousand initial electrons of 10-GeV beam energy. Samples for different incident beam sizes were generated, assuming the transverse incident particle distribution is a two-dimensional gaussian and were used as input data for later simulations.

Capture efficiency of the solenoid focusing system was evaluated by tracking simulations with a step-by-step integration of the equation of motion, including a focusing magnetic field, an accelerating field and a detailed aperture constraints in the capture section [5]. The step size was 0.25 - 1.0 mm. Typical number of the particles after the capture section was three thousand.

To estimate a beam transmission efficiency of the 1.98-GeV positron injector linac, particle tracking was performed with the SAD code [6] in a six-dimensional symplectic manner. The positron focusing system in the linac is a combination of a FODO of singlets and periodic triplet quadrupoles. In Fig.5, a preliminary design of the beam optics and the layout in the linac is shown, as well as an example of the beam transmission efficiency along the linac. Here, the beam optics from the defining collimator till the junction of the three beams and that for the transfer line to the PDR were omitted. In this simulation, an aperture radius in the linac was assumed to be 10 mm and an acceptance cut by the energy and emittance defining collimator, located just after the capture section, were also taken into account.

Finally, PDR acceptance cuts were applied to the sample particles after the tracking simulation in order to estimate the positron yield. The acceptances for PDR injection were assumed to be 0.027 rad.m in the transverse emittance, ±1 percent in the particle energies and 24 mm in the longitudi-

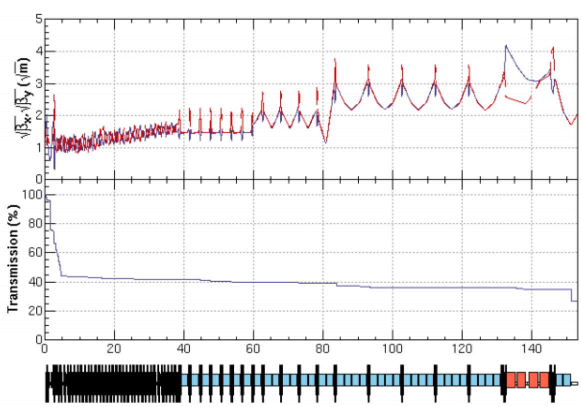

Figure 5: Positron Injector Linac Beam Optics and Beam Transmission

nal position in a bunch. Due to large energy spread of the positrons, approximately 50 % of them were eliminated by the PDR energy acceptance. To improve this efficiency, the single-bunch energy-spread compression system (SBECS) was considered, which has already been used in the KEK B-factory injector linac [7]. This system is composed of the chicane to produce path difference for the particles with different energies and an accelerator section which gives acceleration (or deceleration) to compensate the energy difference in a bunch. As shown in Fig.6, the energy-spread can be compressed with this system and the injection efficiency to PDR was expected to be more than 70 %.

Not only the energy-spread of the positrons in a bunch, but an energy deviations between the bunches due to the transient beam loading along the bunch train is also large. In the positron linac, ΔT multi-bunch energy compensation system (ΔT ECS) is used as in the JLC electron injector linac [2]. Here, the amplitude modulation technique is applied to an input rf pulse into the SLED cavities to obtain the desirable slope of unloaded voltage in the accelerating structure. A combination of two klystrons are needed to modulate the amplitude of rf pulse for the SLED cavities with a constant phase. By using the ΔT ECS, the multi-bunch energy deviation can be negligible compared to the PDR energy acceptance and therefore, it was not included in the tracking simulation.

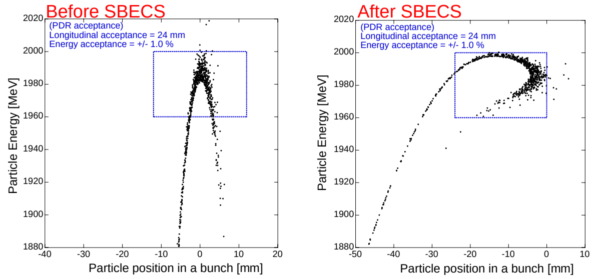

Figure 6: Single-Bunch Energy-spread Compression System

After all the simulations, the positron yield for different numbers of the targets is shown in Fig.7 at each acceptable minimum beam size. The single or two target systems cannot yield sufficient number of positrons. In the case of three target system, the incident beam size can be 2.5 mm in radius and the estimated positron yield at PDR is $Ne^+/Ne^- = 0.99$ and the requirement of the $Ne^+/Ne^- = 0.75$ is satisfied.

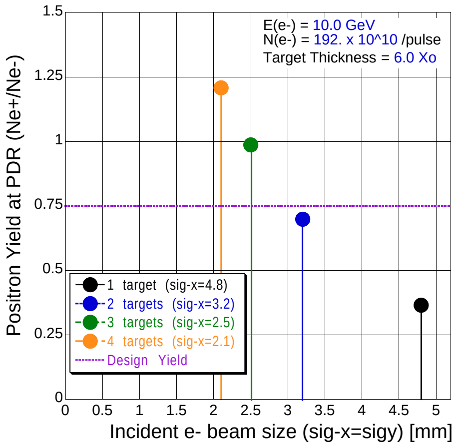

Figure 7: Positron yield as a function of beam size

CONCLUSION

The tracking simulations of the JLC positron source shows that, the multiple target system is inevitable to make the energy density below the threshold of the target damage and to yield sufficient intensity of the positrons. The simulation shows the minimum number of the targets are three. The single bunch energy compression system is effective in improving the injection efficiency to the pre-damping ring.

REFERENCES

[1] ”JLC design study”, By N. Akasaka, *et al.*, KEK Report 97-1, 1997 April

[2] ”JLC Roadmap Report”, February 12, 2003 see http://lcdev.kek.jp/RMdraft/

[3] ”2001 Report on the Next Linear Collider (A report submitted to Snowmass ’01)”, By the NLC collaboration, SLAC-R-571, 2001 June

[4] ”The EGS4 Code System”, By W. R. Nelson, H. Hirayama, D. W. O. Rogers, SLAC-Report-265, December 1985

[5] ”Positron Production at CLIC”, By T. Kamitani, L. Rinolfi, CLIC Note 465, March 2001

[6] ”SAD (Strategic Accelerator Design) Home Page”, By K. Oide, *et al.*, http://www-acc-theory.kek.jp/Accelerator/index.html

[7] ”The KEKB injector linac”, By I. Abe, *et al.*, Nuclear Instruments and Methods in Physics Research Section A, Volume 499, Issue 1, 21 February 2003, Pages 167-190