POSITRON SOURCE FOR THE JLC

H. Ida,*S. Uno,*J. Urakawa,*S. Kawabata,*Y. Takeuchi,*Y. Namito,*H. Hirayama,*A. Miyamoto,*M. Yoshioka

Engineering Research Center, NKK Corpóration
1-1 Minamiwatarida, Kawasaki-ku, Kawasaki-shi, 210 Japan
*KEK, National Laboratory for High Energy Physics
1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305 Japan

Abstract

A simulation program has been developed in order to design an intense positron source for the Japan Linear Collider (JLC). The results of simulations indicate that the positron yield strongly depends on the transverse acceptance of the beam transport system downstream of the target.

Introduction

The JLC is a future electron-positron linear collider with the c.m. energy of 1.5 TeV and the luminosity of $10^{34}cm^{-2}\cdot s^{-1}$, which has been developed in KEK[1]. Since in the linear colliders, the beam after the collision cannot be used again, an intense positron source has to be developed. In case of the JLC, 2.0×10^{10} particles/bunch and 20 bunches/pulse with the bunch spacing of 1.4 nsec, as shown in Fig. 1, is required at an interaction point to realize such a high luminosity. Therefore, we have to generate a pulse intensity of more than 4.0×10^{11} particles/pulse.

There exits two methods to generate such a high intensity positron beam as follows;
(1)An impingement on a thick converter target by high energy electrons of around 30 GeV initiates an electromagnetic cascade shower, then positrons are captured and accelerated as already have been used at SLC[2],[3]. The system consists of an electron linac, a converter target, a phase-space transformer and an acceleration section as schematically shown in Fig. 2.

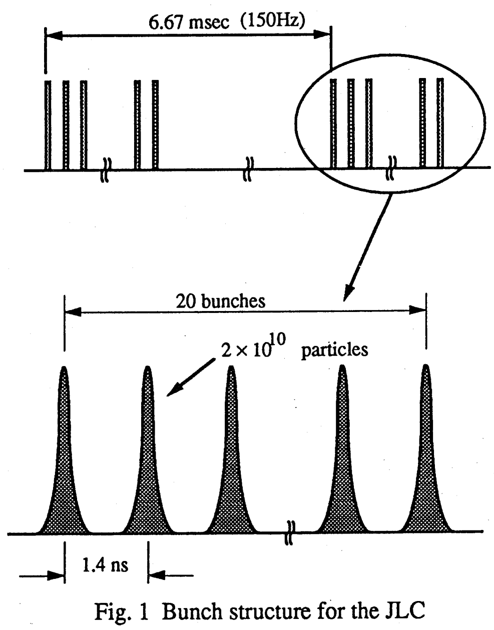

Fig. 1 Bunch structure for the JLC

(2)An impingement on a thin converter target by high energy photons generated through an undulator with use of high energy electron of more than 100 GeV initiates an electromagnetic cascade shower, then positrons are captured and accelerated, as have been proposed by INP(Novosibirsk) and DESY/THD[4]
Maximum intensity of available positrons is limited by thermal problems in the first method. On the other hand, the second method would be used if there is no possibility to generate a required positron intensity by the first method or polarized positron beams are required. A pulse intensity of 3.0×10^{10} particles/pulse have been attained at the SLC positron source[4]. Although the pulse intensity of the JLC positron source is 13 times as compared to that of the SLC, we have decided to adopt the first method.

In order to enhance available positrons by using the method (1), we have to develop positron source design for (a)enhancement of positron yield, (b)enhancement of incident electrons impinged on the target and (c)enhancement transmission efficiency between the target and the damping ring, and between the damping ring and the interaction point. In order to realize these improvements, parameters of the positron source, discussed in following sections, have to be optimized. The complicated system, however, makes analytic calculations difficult except for an idealized case. Computer simulations could provide a way to calculate and optimize the performance of the system. A simulation program for the positron source has been developed in KEK and the study of the JLC positron source has been carried out. The results of the simulations for the JLC positron source are described. We are now constructing Accelerator Test Facility (ATF) to carry out experiments to develop essential technology of the JLC. The calculated results will be verified in the experiments of a prototype positron source.

Positron source for the JLC

In the JLC, a pre-damping ring is adopted to increase the normalized emittance of the positron beam which can be accepted by the damping ring[5]. If we assume that the normalized yield is 0.15 e^+/e^-/GeV and the transmission efficiency between the pre-damping ring and the interaction point is 60%, required pulse intensity becomes 4.5×10^{12} GeV (720 J). Normalized yield is defined as the number of the positrons accepted by the pre-damping ring, divided by the number and the energy (GeV) of the incident electron, so that the assumed normalized yield is comparable to 4.5 positrons generated by a 30 GeV incident electron. The assumed yield is three times higher than the normalized yield of SLC and the required pulse intensity exceeds an allowable pulse intensity of the solid metal target of around 320 J obtained by the operational results of SLC positron source.

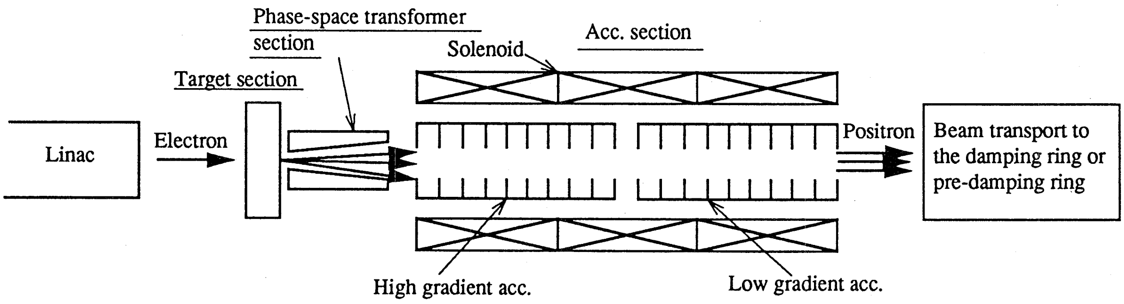

Fig.2 A schematic diagram of the positron source

The methods of simulations

The electromagnetic shower cascade in the converter target is simulated with the Monte Carlo program, EGS4[6]. This program provides position and momentum of positrons at the exit of the target. The positrons emerging from the target are then tracked through the phase-space transformer and accelerating sections with use of Runge-Kutta method. In the phase-space transformer section, magnetic field produced by the adiabatic device as shown below is taken into account[7].

$$B_z = \frac{B_0}{1+\mu z},$$

$$B_r = -\frac{r}{2}\frac{dB_z}{dz} + \frac{r^3}{16}\frac{d^3B_z}{dz^3}$$

In the accelerating section, an acceleration in a sinusoidal longitudinal electric field is assumed as follows;

$$E_x = E_y = 0,$$

$$E_z(t) = E_0 \sin(\omega t - kz + \phi)$$

$$\omega = 2\pi\nu \quad ; \nu = 2856\text{MHz}$$

$$k = \omega / c$$

ϕ : Initial phase

The positrons accepted by the phase-space transformer section have a large spread in energy and concentrate less than 10MeV. After the accelerating section, the positrons slip in phase. Furthermore, the non-zero transverse momenta of positrons results in additional phase slip because the helical motion has a longer path length than straight motion down the axis. An acceleration field is, therefore, taken into account of time dependence in this simulation.

The results of simulations

At first, parameters of the positron source derived from those of the SLC, shown in right column in Table 1, were simulated. The simulated positron yield at various positions are given in the column of results in Table 1. At the exit of the target, there exists 66 positrons by a 33 GeV incident electron, however 5.2 positrons can emerge from the accelerating section. Among them, 2.8 positrons are within the transverse acceptance if we assume the transverse acceptance of the beam transport between the positron source and the pre-damping ring is $\gamma\varepsilon = 3\times10^{-3}$ rad·m. Finally, 1.8 positrons are within the energy acceptance of the pre-damping ring ($\Delta E/E = \pm1\%$).

Since the simulated positron yield of 1.8 e^+/e^- is insufficient for the required yield, the parameters is then modified. As the direction of the modification, a)enlargement of the incident beam size and the iris aperture of the accelerating section, b)optimization of the initial acceleration phase, c)enlargement of the magnetic field in the phase-space transformer and solenoidal field in the accelerating section were considered. The obtained parameters and results are shown in right column in Table 1. Figure 3 represents the calculated longitudinal emittance of the positron at several positions. At the exit of the accelerating section, 2.4 positrons are within the transverse and energy acceptance. Since the incident beam spot size was enlarged from σ=0.8 mm to 1.2 mm, normalized thermal heat load for the target is expected to be reduced and the incident beam energy is hence able to be increased. If the thermal stress is simply relaxed as proportional to the incident beam area, we could increase the incident beam intensity by a factor of 2.25 ($=(0.8)^2/(1.2)^2$) and the number of available positrons are also increased by a factor of 2.25.

Table 1 Preliminary parameters and the simulated results for the SLC-type and JLC positron source

	SLC-type	JLC(tentative)
Conditions		
(Target section)		
Material	Tungsten	Tungsten
Thickness	6 R.L.=21mm	6 R.L.=21mm
Incident beam energy	33GeV	33GeV
Incident beam spot size	σ=0.8mm	σ=1.2mm
(Phase-space transformer section)		
Peak mag. field	6.8 T	8.0 T
Length	10cm	10cm
(Accelerating section)		
Accelerating field	50MV/m (15MV/m)	50MV/m (15MV/m)
Length	1.5m (3.0m)	1.5m (3.0m)
Dia. of beam hole	1.8cm	2.6cm
Solenoidal field	0.5 T	0.8 T
Initial phase	90°	90° [-10°shifte after 120 MeV]
Simulated results		
e^+/incident e^-		
At the exit of the target	65.9	65.9
At the exit of phase-space transformer section	34.9	34.9
At the exit of accelerating section	5.2	15.3
After emittance cut ($\gamma\varepsilon=3\times10^{-3}$ rad·m)	2.8	3.1
After energy acceptance cut ($\Delta E/E = \pm1\%$)	1.8	2.4

( ) :Low gradient acceleration section

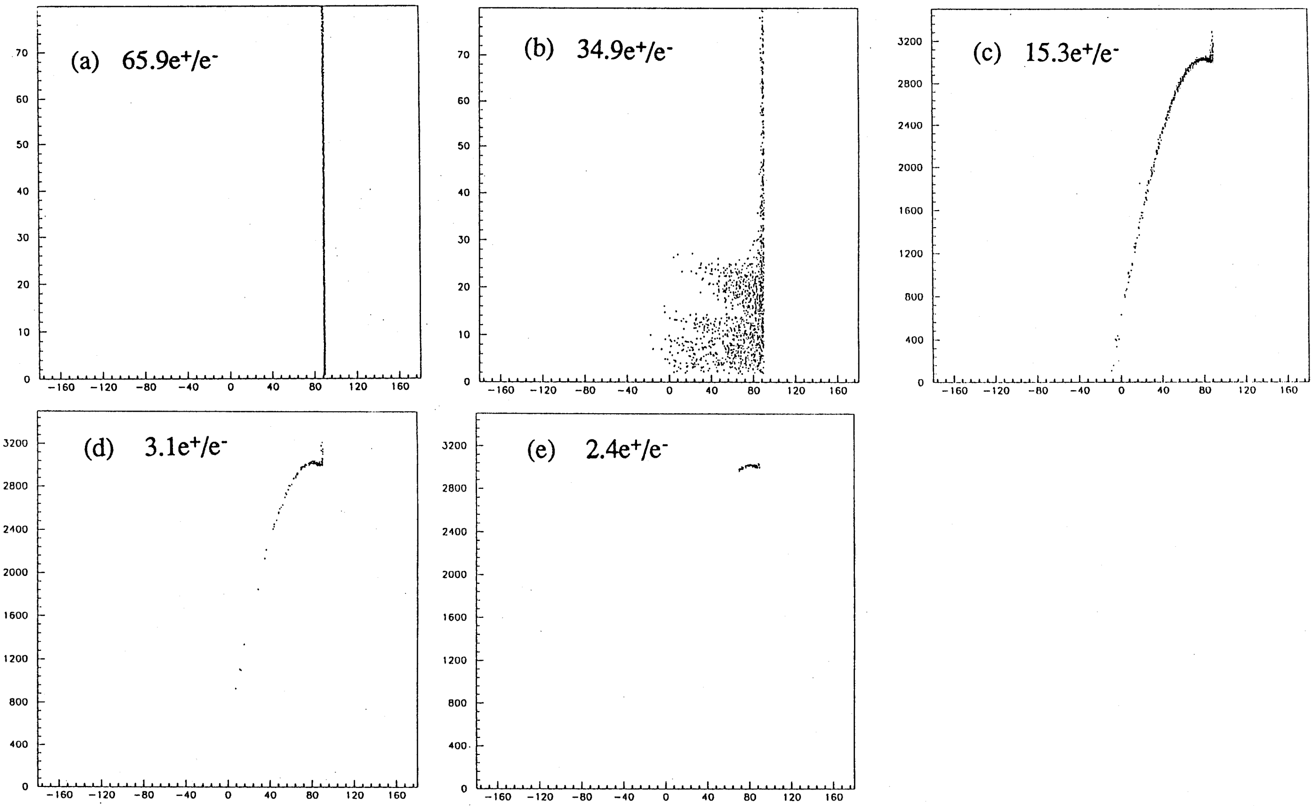

Fig.3 The calculated longitudinal emittance of the positron at several positions (a) at the exit of the target, (b) at the exit of the phase-transformer section, (c) at the exit of the accelerating section, (d) after emittance cut ($\gamma\varepsilon=3\times10^{-3}$ rad·m), (e) after energy acceptance cut ($\Delta E/E=\pm1\%$). The horizontal axis represents phase with respect to the accelerating field. The vertical axis represents longitudinal momentum in units of m_0c.

Figure 4 gives a positron yield in changing the acceptance of the beam transport system. As indicated in this figure, the positron yield greatly depends on the transverse acceptance downstream of the target, not on the energy acceptance of the pre-damping ring. If we design the beam transport system whose transverse acceptance is $\gamma\varepsilon=1\times10^{-2}$ rad·m, the positron yield would be nearly 6.0.

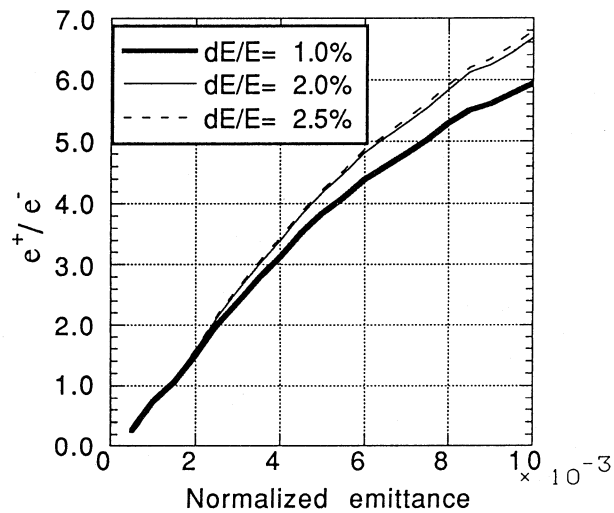

Fig. 4 Positron yield in changing the acceptance of the beam transport system followed by the target.

Summary

We have developed simulation code for the design of the positron source. The direction to develop the JLC positron source are revealed as follows;

(1)To enhance the transverse acceptance of the beam transport system($\gamma\varepsilon=1\times10^{-2}$ rad·m.), but enhancement of the energy acceptance is not so efficient.

(2) To design the phase-transformer and acceleration section in order to enlarge the incident beam spot size for relaxation of the thermal stress at the target

We have to carry out further simulations and thermal analysis for the target and design the beam transport system.

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