Positron Accumulator Ring for Linear Collider and R&D Plan

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Abstract

The possibility of the complementary positron source using accumulator ring is discussed for the generation of high intensity multi-bunch positron beam for the Japan Linear Collider (JLC). The key features of this scheme include accelerating positrons at an L-band frequency (1428 MHz) to get the high normalized yield of $0.5e^+/e^- \cdot GeV$ and using several parallel positron targets & positron accumulator rings to relax the high radiation activity. For the reliability, maintenability and improved source efficiency, the design uses several parallel positron generation systems adequately shielded from each other. The invariant transverse acceptance of the capture system is $0.06m \cdot rad$, ensuring an adequate positron beam intensity for the JLC. Since there are many challenging R&D's to establish the positron normalized yield of 0.5, the Positron Factory using the positron target system of the ATF is proposed with 200MeV small accumulator ring, L-band high gradient structures for acceleration upto 200MeV & deceleration until 2MeV, and an efficient moderator structure.

1 Introduction

The proposed JLC positron source based on the existing SLC positron system 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, an S-band positron linac, and a pre-damping ring [1,2]. The JLC is designed to collide a 85-bunch positron beam with an identical electron beam with a bunch intensity as high as 0.7×10^{10} particles for each machine pulse [3]. The beam pulse intensity requirement for the JLC is such that 20-times more positrons need to be produced per pulse, as compared to the operating condition at SLC. There is the primary challenge in designing the JLC 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 JLC source. Table 1 lists the important parameters for the JLC positron source, along with the NLC-I positron source parameters for comparison [4].

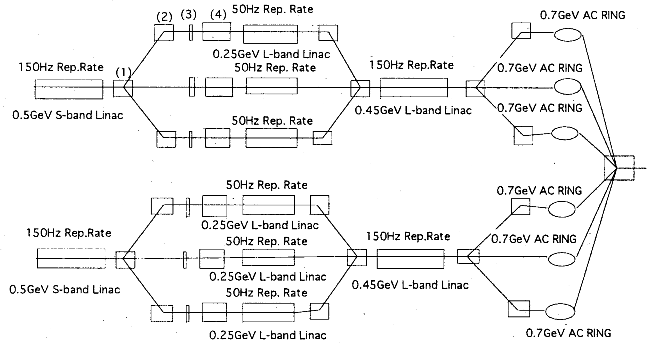
In this paper we present other conventional scheme that is reasonably conservative and uses only existing technologies. New scheme for complementary positron source is described in the following section. In section 3 the R&D plan on the positron generation and accumulation for the linear collider using the KEK-ATF is proposed [5]. It is applicable to the high density positron factory. So, discussion on some applications of proposed positron factory is given in final section.

Table 1
JLC and NLC-I Positron Source Parameters

Parameters	JLC	NLC-I
Drive Electron Energy (GeV)	10.0	3.11
No. of Bunches per Pulse	85	90
Bunch Intensity(10^{10})	0.7	1.5
Repetition Rate (Hz)	150	180
Beam Power (kW)	147	121
Beam σ on Target (mm)	1.2	1.2
Pulse Energy Density ($10^{11}GeV/mm^2$)	6.6	4.6
Positron Target Material	$W_{75}Re_{25}$	$W_{75}Re_{25}$
Thickness (R.L.)	6	4
Tapered Field (T)	1.2	1.2
Uniform Field (T)	0.8	0.5
Flux Concentrator Field (T)	5.8	5.8
Flux Concentrator Minimum Radius (mm)	3.5	4.5
Accel. RF Frequency (MHz)	2856	1428
Accel. Gradient (MV/m)	30	25
Minimum Iris Radius (mm)	13	20
Edge Emittance ($m \cdot rad$)	0.027	0.06
Positron Yield per Electron	2.1	1.4
Positron Bunch Intensity(10^{10})	1.5	2.1
Positron Normalized Yield	0.21	0.45

2 Complementary Positron Source

The JLC positron source is of a conventional type based on $e^\pm$ pair production from an electromagnetic shower created in a thick, high-Z target upon bombardment by high energy electrons. The reliability of the positron production and capture system is specially important since the high radiation levels in these areas would prevent human access for quick repair in case of hardware failure. A effective way to increase the reliability is to build several identical positron generation systems, to reduce the electron beam power on the target and to increase the capture efficiency. Several positron generators housing identical positron production and capture systems that are adequately shielded from each other will be built. Fig. 1 shows the schematic layout of the complementary positron source. This system consists of two drive 0.5-GeV S-band linac, several positron targets & positron accumulator rings and L-band linac to the rings. In order to increase the positron capture efficiency, the introduce of the L-band high gradient linac after the positron target, which is the same one as the NLC design, is essential for the proposed new scheme. Same positron target and capture system as the NLC design except for the thickness of the target will be adopted. The thickness of the positron target is 3.6 radiation length in the case of the drive electron beam energy of 0.5 GeV. The development of C-band linac components has been proceeded as the back-up option for the JLC main linac. In this case, 4 parallel positron generation systems are necessary.



JLC X-band Positron Generator System using Acuumulator Ring and L-band Linac

(1): Bipolar Pulse Magnet (2): Bending Magnet (3): Positron Target (4): Flux Concentrator

Fig. 1 Schematic layout of the complementary positron source.

The drive beam accelerator uses S-band (2856 MHz) RF for acceleration and has an injector consisting of a thermionic gun, two subharmonic and one S-band bunchers similar to those in the ATF injector. Beam loading compensation in the accelerator will be accomplished using pairs of structures operated at about 1 MHz above and below the main RF frequency, i.e., the so-called $\pm\Delta f$ beam loading compensation method. The L-band design for the JLC positron capture and booster accelerators is the key to achieving the order of magnitude higher positron beam intensity over that of the SLC positron source. This design is same one as the NLC positron source [6].

2.1 *Positron Accumulation*

As in the SLC positron source, $W_{75}Re_{25}$ is chosen as the target material because of its high $e^{\pm}$ pair production efficiency and excellent thermo-mechanical properties. The input electron beam can be directed to each system via bending magents that are isochronous and linearly achromatic. The 250 MeV positron beam after the capture accelerator from each system is directed into a common 0.45 GeV L-band linac. The first bending magnet following the capture accelerator also serves to separate the captured electrons from the positron beam. Two identical systems allow to be stacked once in RF-buckets already containing positrons.

2.2 *Accumulator Ring*

Minimum circumference of the ring is determined by the length of bunch train and kicker rise time. Transverse damping time is proportional to the ring circumference and the bending radius. Since normal conducting bending field of 2.7[T] is obtained at the routine operation of Aurora-2, the design of the accumulator ring is based on the magnet design of the Aurora-2 [7]. This bending magnet has the gap of 42 mm and good field region of 60 mm. The ring has a racetrack configuration and two 30° & one 120° bending magnets in each arc section to remove dispersion in two straight sections. Table 2 gives preliminary design parameters of the positron accumulator and the drive electron beam. The electron beam power to the target is less than 1/12 comparing the proposed JLC positron source in the Table 1. These accumulator rings are designed using 6 bending magnets for simplicity. The value of the single-bunch threshold indicates large impedance budget. So, the momentum compaction factor can be reduced by increasing the number of the bending magnets with the constant bending field. The RF voltage and equilibrium emittance will be reduced by the optimization on the number of the bending magnets. However, the development on short high field bending magnet will be required.

Table 2
Preliminary Design Parameters of Positron Accumulator and Drive Electron Beam

	JLC-X	JLC-C
Positron Accumulator:		
Beam Energy (GeV)	0.7	0.7
Circumference (m)	42.0	66.4
714MHz RF Voltage (MV)	6.4	4.0
Bending Field (T)	2.66	2.66
Bunch Length (mm)	3.4	4.3
Energy Spread (%)	0.064	0.064
Horizontal Damping Time	8.3 msec	13.2 msec
Single-bunch Threshold (Ω)	2.14	1.09
Positron Bunch Intensity	1.4×10^{10}	2.2×10^{10}
Drive Electron Beam:		
Electron Energy (GeV)	0.5	0.5
No. of Bunches per Pulse	85	72
Bunch Intensity (10^{10})	2.8	4.44
Repetion Rate (Hz)	150	100
Beam Power per Pluse (J)	190.4	255.7
Beam Power (kW)	9.52	12.8

The positron bunch intensity in the Table 2, which is two times the required intensity of 0.7×10^{10} at the interaction point, includes 50% additional beam losses in downstream accelerator components.

3 R&D Plan

It is necessary to investigate the feasibility on the normalized yield of $0.5e^{+}/e^{-} \cdot GeV$. The essential R&D is to establish the technology on the high gradient L-band structure and the positron capture system. The device including the flux concentrator, the tapered field solenoids and the target was made as the ATF positron source. The ATF linac is designed including the positron-source test facility before the linac beam dump [5].

The L-band linac with the accelerating gradient of 25 MV/m should be constructed after the positron target. There is space to install about 10 m-long linac and a small ring near the end of the ATF linac. Fig. 2 shows the 200 MeV accumulator ring to stack the positron beam with the 0.06 edge emittance. Inner size of the vacuum chamber for the positron accumulator is horizontally 60 mm and vertically 35 mm in full width. The vertical width of 50 mm is necessary to accept the beam with the edge emittance of $0.06m \cdot rad$. It is difficult to enlarge the gap of the bending magnet because the bending field is inversely proportional to the gap. The R&D on normal conducting bending magnet which has 60 mm gap and 2.1 T is important.

The essential R&D regarding the accumulator ring is to study the beam acceptance. Table 3 shows the design parameters of the 200 MeV positron accumulator and the ATF drive electron beam. Further detailed analyses should be carried out concerning the L-band accelerator structures, beam instability, reliability of the components, and rotating target.

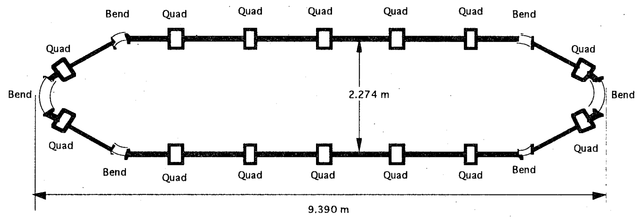


Fig. 2 Accumulation Ring for Positron Factory.

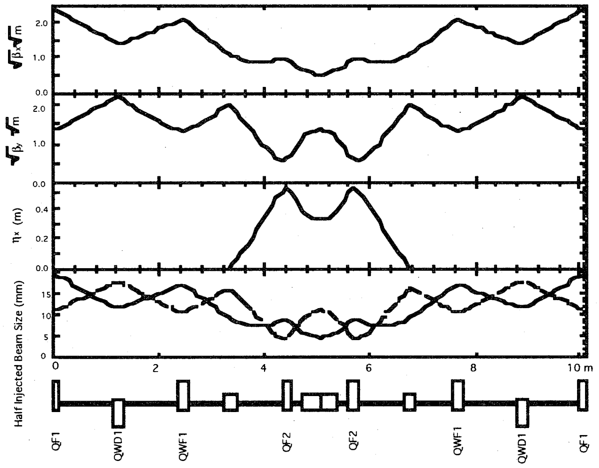


Fig. 3 Lattice Parameters of Half Ring and Half Edge Size of Injected Beam.

4 High Density Positron Factory

The L-band linac can decelerate the bunched beam with the normalized emittance of $5 \times 10^{-5} m \cdot rad$ until 2 MeV. About 10^8 slow positrons per pulse are obtained using the moderator assembly with a honeycomb-like structure enclosed by reflectors which was proposed by S. Okada et. al. [8]. The 2 MeV slow positron can be focused on the moderator until the beam size of about 1 mm(rms). This high density positron factory will give the promotion of precise experiments for material science and the possibility of the experiment on Bose-Einstein condensation of positronium using laser cooling [9].

Table 3
Design Parameters of 200MeV Positron Accumulator and ATF Drive Electron Beam

Positron Accumulator:	
Circumference (m)	21.0
714MHz RF Voltage (MV)	0.4
Bending Field (T)	2.08
Bunch Length (mm)	4.5
Energy Spread (%)	0.064
Horizontal Damping Time	70 msec
Touschek Lifetime	78 sec
Single-bunch Threshold (Ω)	0.275
Positron Bunch Intensity	3.1×10^{10}
Normalized Emittance of Beam	$5 \times 10^{-5} m \cdot rad$
ATF Drive Electron Beam:	
Electron Energy (GeV)	1.54
No. of Bunches per Pulse	20
Bunch Intensity (10^{10})	2.0
Repetion Rate (Hz)	6.25
Beam Power per Pluse (J)	98.6
Beam Power (kW)	0.62

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