DESIGN OF AN INTENSE POSITRON SOURCE FOR LINEAR COLLIDERS

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Abstract

The Japan Linear Collider (JLC) requires an intense positron source of 8×10^{11} particles per rf-pulse. A computer simulation reveals the possibility of such an intense positron source using "conventional" technology. A prototype positron source has been designed and installed downstream of a 1.54 GeV S-band linac in Accelerator Test Facility (ATF) in order to carry out experiments to develop the essential technology for the JLC. The simulated results will be tested in experiments with the prototype positron source.

Introduction

The JLC-I requires an intense positron source of $0.7\sim1.7\times10^{10}$ particles per bunch and 46~90 bunches per rf-pulse at an interaction point [1]. The maximum positron intensity of the JLC-I positron source amounts to be 8×10^{11} particles per rf-pulse, which is 20 times higher than that of SLC positron source. In order to achieve such an intense positron source, we have developed a computer simulation code for a positron source and detailed simulations have been carried out for the JLC positron source [2]. We have designed the JLC positron source with a conventional positron production method of injecting high-energy electrons on a converter target to initiates an electromagnetic cascade shower. In order to relax the limitation of the incident electron energy density due to thermal stress in the converter target, the incident beam radius is enlarged within the range so as not to reduce the positron capture efficiency. A pre-damping ring and beam transport system to the pre-damping ring, which have a large transverse acceptance, play important roles for a high capture efficiency.

As for the ATF positron source, there exist some limitations on available space for experiments, incident beam energy, radiation shield and so on, we concentrate on engineering feasibility and verification of simulation code as a purpose of the experiments using prototype positron source.

Simulations of a positron source performance for the ATF

An electromagnetic cascade shower in the converter target is simulated by a Monte Carlo program called EGS4 [3]. The positrons emerging from the target are then tracked through the phase-space transformer and accelerating sections in magnetic and electric field using the Runge-Kutta method. The overall conversion efficiency including the transmission efficiency to the interaction point is assumed to be 0.5 per an incident electron in these simulation. Figure 1 shows schematic view of a positron source.

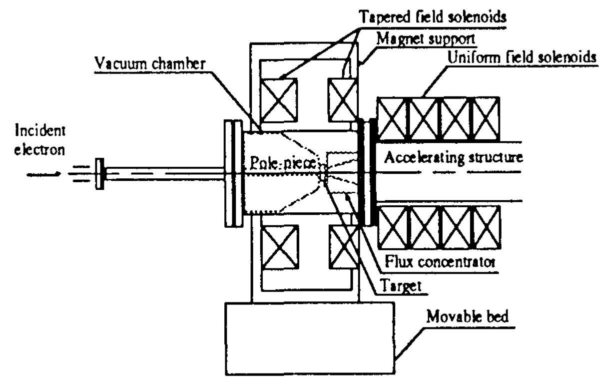

Fig. 1 Schematic view of a positron source

Optimized parameters for the ATF positron source are summarized in table 1. An incident electron intensity is limited to be 6.25×10^{9} e^{-}/s due to a radiation dose around the positron source with a 1-m-thickness concrete and a 7-cm-thickness additional lead shield.

For an intense positron source of linear colliders, the number of produced positrons can be increased by enlarging a radius of injected electron beam because the incident electron density is relaxed according to an increase of an area of the incident electron beam. A limitation of electron energy density has been obtained to be 2.0×10^{12} GeV/mm^2 by experiments using SLC positron source [4]. The electron energy density of the ATF positron source is, however, well below the limit, it is not required for the ATF positron source to enlarge the incident beam radius to suppress the thermal stress at the target and increase the incident electron density. According to beam optics calculations, an rms beam radius onto the target could be 1.2 mm by four quadruple magnets upstream of the positron source. As for a positron capture efficiency, the incident beam radius is preferred to be small. If we focus the incident electron beam to 1.2 mm, positron capture efficiency is reduced by 10 % compared to a case of incident beam without spread.

Tungsten is a suitable material for the converter target because of its high melting point. A 4-radiation-length tungsten shows the highest positron capture efficiency for an incident electron of 1.54 GeV.

Positrons emerging from the target can not be accelerated efficiently since they have large transverse momenta at around 3 MeV/c. They should be transformed in phase-space, (x,Px), to be acceptable for accelerating section downstream, by using an adiabatic device [5]. This system makes a slowly varying magnetic field along the beam axis with a flux concentrator [6], followed by a constant solenoidal magnetic field extending over some accelerating sections. According to simulations, initial magnetic field of 8 tesla and a constant solenoidal magnetic field of 0.8 tesla is found to be a good compromise between the attainable positron capture efficiency and engineering problems to be solved. In the ATF positron source, those magnetic field are determined as same as those of the JLC positron source while a length of an adiabatic device has been optimized.

The energy of the positrons accepted by the phase-space transformer section have a large spread at around 4 MeV. The positrons slip in phase during the acceleration. Therefore, positrons should be accelerated by high accelerating gradient. On the other hand, large aperture of accelerating structure is desirable in view of positron capture efficiency. In the ATF design, there would be a serious problem of an available space, length of an accelerating structure should be less than 2 m .

TABLE 1
Simulated Parameters of the ATF Positron Source

Incident Electron Beam		
Energy	1.54	GeV
Intensity per rf-pulse	6.25×10^9	
rms beam radius	1.2	mm
Beam power	0.04	kW
Target Section		
Material	W-Re	
Thickness	14	mm
Phase-space Transformer Section		
Initial magnetic field	8	T
Length	120	mm
Accelerating Section With Solenoids		
Accelerating frequency	2856	MHz
Repetition rate	150	Hz
Accelerating gradient	30	MeV/m
Structure length	1.5	m
Iris diameter at the exit	26	mm
Constant solenoidal field	0.8	T

Design of the ATF Positron Source

Simulations described above have revealed basic parameters of the ATF positron source. The design of the JLC and ATF positron source has been derived from the SLC positron source. Figure 2 shows cross-sectional view of the ATF positron source. The positron source has a stationary target however it also has basic mechanism for a rotating target. It could become a rotating target if an assembly of cooling water inlet and outlet is changed. The whole target assembly could be moved transversely when positron production experiment is not performed.

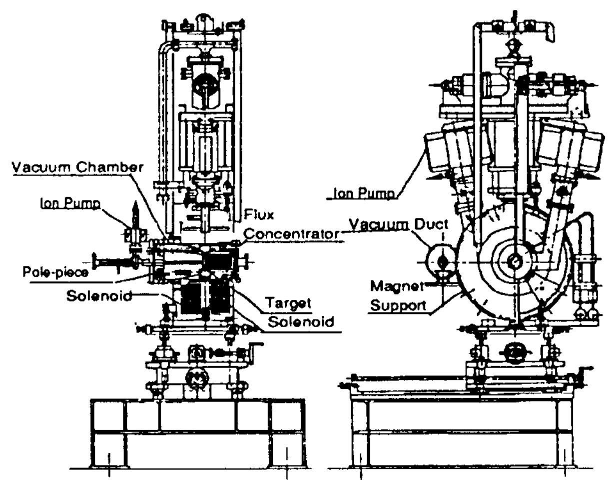

Fig. 2 Cross-sectional view of the ATF positron source

It is necessary for an adiabatic device to produce initial solenoidal field of 8 tesla just after the target . Such high magnetic field could be achieved only by a pulsed flux concentrator. It is made of oxygen-free copper block with conical open inside as shown in figure 3. Copper conductor is brazed outside of the block. The gap between turns should be around 200 µm which is less than the skin depth of copper at 100 kHz. This gap has been made by wire discharge machining. The solenoidal field could not be leak from the gap, the field would be *concentrated* inside the flux concentrator. Table 2 summaries main parameters of the flux concentrator.

TABLE 2
Main Parameters of the ATF Flux Concentrator

Repetition rate	maximum 25	Hz
Inductance	1.1	µH
Peak current	16	kA
Peak voltage	12	kV
Frequency	100, half sin-wave	kHz
Power dissipation	0.6	kW

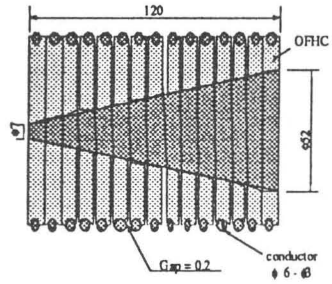

Fig. 3 Schematic cross section of a flux concentrator for the ATF

In order to enhance the magnetic field just after the target, DC solenoidal field would be located around the vacuum chamber where the target is located. Tapered field solenoids comprises two DC solenoids with pole piece. These solenoids produces maximum magnetic field of 1.2 tesla at the entrance of the flux concentrator. Figure 4 shows calculated magnetic field of the tapered field solenoids by POISSON. If there exists a dip of the magnetic field as shown in fig. 4, it would reflect positrons as a mirror. Configuration using large bridge coils located both ends of solenoids surrounding accelerator structure is, therefore, required to suppress the dip. Furthermore, it should be considered with the design of rf-power feed to the accelerator structure and flanges to minimize the distance between the chamber and the accelerating structure. Table 3 summaries main parameters of the tapered field solenoids.

TABLE 3
Main parameters of the tapered filed solenoids

	Solenoid 1 (upstream)	Solenoid 2 (downstream)
Inner diameter (mm)	280	250
Outer diameter (mm)	560	570
Height (mm)	100	100
Number of turns	140	160
Current (A)	900	900
Voltage (V)	54	60
Power dissipation (kW)	49	54

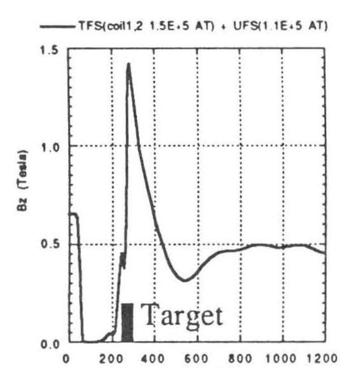

Fig. 4 Calculated magnetic field of the tapered field solenoids

Summary

Figure 5 shows a prototype positron source installed downstream of the ATF S-band linac. Beam transport between the linac and the positron source is under construction. Beam diagnostics for experiments would be installed before a construction of the linac has been finished. After the experiments using the linac has been completed, positron production experiments is going to be performed in order to confirm the simulation code and develop the key technology for the positron source of the JLC.

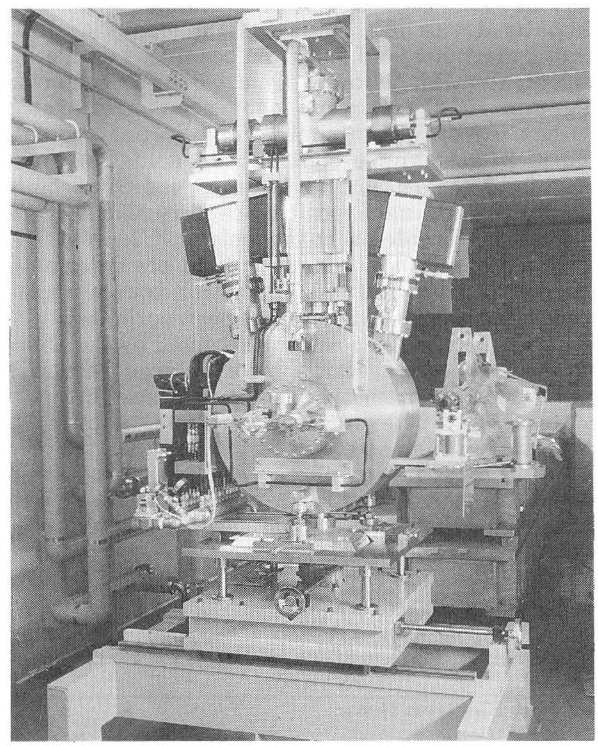

Fig. 5 A prototype positron source installed downstream of the ATF S-band linac

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