

AN OPTIMIZATION OF ILC POSITRON SOURCE FOR ELECTRON-DRIVEN SCHEME

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Abstract

International Linear Collider is a future accelerator to find new physics behind the electroweak symmetry breaking by precise measurements of Higgs sector, Top quark, and so on. ILC has capacities to reveal new phenomena beyond Standard model, such as Supersymmetry particles and dark matters. In current design of positron source, undulator scheme is adapted as a baseline. In the scheme, positrons are generated from gamma rays through pair-creation process in Ti-alloy target. Generations of the gamma rays by the undulator radiation requires more than 130 GeV electrons. Therefore, a system demonstration of the scheme is practically difficult prior to the real construction. Consequently, it is desirable to prepare a technical backup of this undulator scheme. We study an optimization of positron source based on the conventional electron-driven scheme for ILC. In this scheme, positron beam is generated by several GeV electron beam impinging on W-Re target. Although heavy heat load and destruction of the target is a potential problem, it can be relaxed by stretching the effective pulse length to 60 ms instead of 1 ms, by a dedicated electron linac for the positron production. In this report, a start-to-end simulation of the electron-driven ILC positron source is performed. Beam-loading effect caused by multi-bunch acceleration in the standing wave RF cavity is also considered.

INTRODUCTION

International Linear Collider (ILC) is an electron and positron collider, which has a total length of 33 km, with a center-of-mass energy of 500 GeV (first phase). ILC Technical Design Report was published in 2013 [1]. In the report, positrons are generated by undulator scheme as the baseline. In a helical undulator, polarized electron beam radiates gamma rays. The gamma rays are irradiated on a Ti (titanium) alloy target, and they are converted to polarized positrons through the pair-creation process. To obtain an enough amount of positrons, the gamma ray energy has to be more than 10 MeV, which requires a 150 GeV driving electron beam with a 10 mm undulator period. Therefore, the high-energy electron beam are shared by the gamma ray generation in the undulator and the collision with the positron. This undulator scheme has never been in operation for an accelerator, and it is difficult to demonstrate the system practically prior to the construction because more than 100 GeV electron beam is necessary as the positron driver. Therefore, a backup is desirable to reduce unknown technical risks.

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The strongest candidate of the positron source as a backup is the conventional electron-driven scheme. In this conventional scheme, a several-GeV electron beam impinges on a heavy metal target. Gamma rays by Bremsstrahlung process are converted to positrons through the pair creation. In this scheme, the positrons cannot be polarized even if electron beam is polarized. According to the SLC experiments, the peak energy deposition density (PEDD) in the target should be less than 35 J/g [2–4] to avoid any damage to the target. The electron-driven positron source for the ILC was designed in Ref. [5]. In this design, a dedicated electron linac is assumed and the positron is generated in 63 ms out of 199ms which is ILC pulse interval for the collision. The generated positrons are stored on DR (Damping Ring) in 136 ms for the damping and sent to the main linac for the collision in the last 1ms. By the stretching of the beam pulse, the heat load on the target can be reduced by a factor 60. The electron-driven positron source for ILC can be accommodated in the tunnel designed for the undulator positron source, because the tunnel is wide enough. The compatibility of both schemes is one of the hottest topic in LCC (Linear Collider Collaboration). [6].

Our aim is to show that an enough number of positrons are obtained in DR acceptance by keeping PEDD less than 35 J/g under realistic parameters. By studying the yield as a function of various conditions, the design has been optimized [7]. In addition, effects caused by multi-bunch acceleration (beam-loading) and its compensation are considered in this report.

POSITRON SOURCE STRUCTURE AND REQUIREMENT

Electron-driven positron source consists of an electron driver linac, a positron production target, an AMD for transverse momentum suppression, a positron injector linac up to about 200 MeV, a chicane to remove positrons with a large momentum deviation and electrons, a positron booster up to 5.0 GeV, and an Energy Compression System (ECS) section as shown in Fig. 1. DR stored once the generated positron for the damping and the damped beam is sent to the main linac. The transverse DR acceptance (dynamic aperture) is $\gamma A_x + \gamma A_y < 0.07$ m, where γ is the Lorentz factor, and A_x and A_y are action values in the horizontal (x) and vertical (y) directions, respectively. The longitudinal acceptance is expressed as

$$\left(\frac{z}{0.035}\right)^2 + \left(\frac{\delta}{0.0075}\right)^2 < 1, \quad (1)$$

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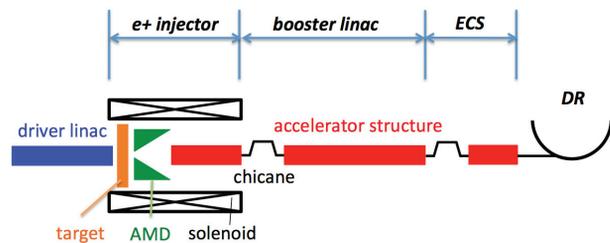


Figure 1: A schematic layout of the electron-driven positron source for ILC.

where z and δ are the longitudinal position deviation and relative energy deviation, respectively [1]. The electron beam energy and bunch intensity of the driver linac are typically 6.0 GeV and 2.0×10^{10} , respectively. The target is typically a 14-mm-thick W-Re (tungsten rhenium) alloy. As a design criterion of the ILC, a 50% margin on the number of positrons at the DR is desirable by assuming some beam loss; namely, 3.0×10^{10} positrons per bunch have to be obtained in the DR acceptance. Additionally, PEDD has to be less than 35 J/g to avoid any damage on the target. The positron yield is defined as ratio of the positrons in DR acceptance normalized by number of incident electron to the target. The higher yield is good for less technical risks, higher electric power efficiency, less radio activity, less beam-loading in the injector, etc.

The electron linac is operated at 300 Hz. The linac is operated only during 63 ms out of 199 ms inter-pulse of ILC main pulse, 5Hz. In the 63 ms duration, there are 21 macro-pulses repeated in 300 Hz. As shown in the left figure of Fig. 2, each macro-pulses contain three mini-trains. One train contains 44 bunches with a 6.15 ns spacing, and the train interval is 100 ns. This pulse structure is a copy of that in DR and the 100 ns spacing is necessary to prevent electron cloud instability in DR. Totally, one macro-pulse lasts 1 μ s. Considering electric power efficiency, normal conducting RF system, which filling time is μ s order, is reasonable. The average beam current of the macro-pulse is about 0.5 A and the beam-loading effect in the macro-pulse is not negligible. The triplet pulse is injected to the DR with usual μ s order kicker, and extracted to the main linac with a fast kicker to match the time structure of electron bunches in the main linac.

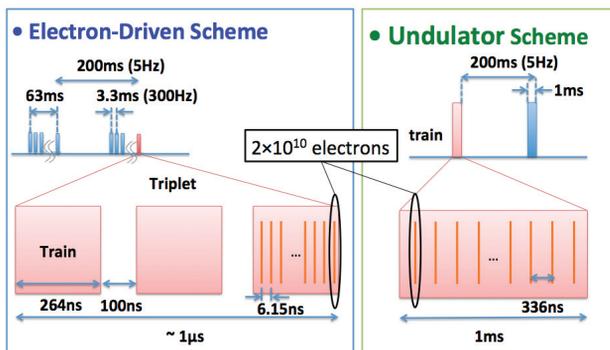


Figure 2: Multi-bunch structures on the electron-driven scheme (left) and on the undulator scheme (right).

Table 1: An Optimum Parameter Set. Aperture Values Indicate the Radius

Parameter	Value	Unit
Drive beam energy	6.0	GeV
Target thickness	14	mm
Beam size (RMS)	4.0	mm
AMD peak field	5.0	T
R_{AMD}	6	mm
Accelerator gradient (injector)	18	MV/m
Accelerator gradient (booster, ECS)	20	MV/m
Injector L-band accelerator aperture	20	mm
Booster L-band accelerator aperture	17	mm
Booster S-band accelerator aperture	10	mm
ECS L-band accelerator aperture	17	mm
Solenoid	0.5	T
PEDD	27	J/g
# of electrons as drive beam / bunch	2.3	10^{10}

POSITRON CAPTURE SIMULATION

Particle tracking simulation is performed from the positron generation target to the DR. The lower accelerator gradient is better for electric power efficiency, less technical risks, but the higher gradient is better for the positron yield. Fig. 3 shows the yield vs. average accelerator gradient of the injector. In the figure, the yield tends to increase as the average accelerator gradient increases, but the yield gain is not great. 18 MV/m is assumed in this report. Table 1 shows an optimum parameters used in a typical tracking simulation.

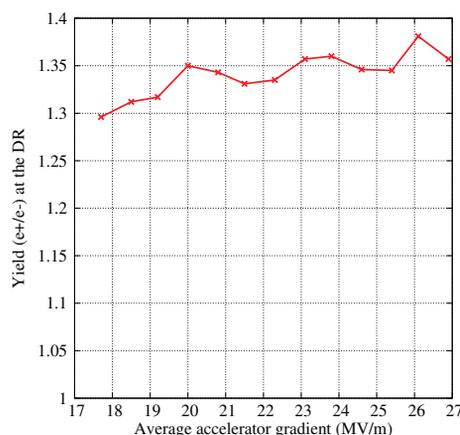


Figure 3: Yield at the DR depended on average accelerator gradient.

MULTI-BUNCH BEAM-LOADING

Beam-loading in the injector section is considered in this section. Injector L-band accelerator aperture in radius is 20 mm, which is realized only by standing wave RF cavity with a reasonable power efficiency. Transient beam-loading on

the standing wave cavity is expressed as Ref. [8],

$$V = \frac{1}{1 + \beta} \left[2 \left(1 - e^{-t/T_0} \right) \sqrt{\beta P_0 r l} - i r l \left(1 - e^{-(t-t_b)/T_0} \right) \right], \quad (2)$$

where V is voltage of a RF cavity, β is coupling constant, P_0 is input power, r is shunt impedance, l is RF length, i is beam current, t_b is time when the beam current turned on, T_0 is filling time which is defined as the required time to build up the field $(1 - 1/e)$ times steady state field:

$$T_0 = \frac{2Q_0}{\omega(1 + \beta)}, \quad (3)$$

where Q is quality factor. From the fact that variable t depends only on exponential part of Eq. (2), proper t_b selection can give constant voltage of the RF cavity; t_b is satisfied following equation,

$$t_b = T_0 \ln \left(\frac{i}{2} \sqrt{\frac{r l}{\beta P_0}} \right). \quad (4)$$

In the injector, the beam-loading effect is four times as large as that of the positron booster because electrons and positron with a large deviation which are removed by the chicane, are still alive. Beam-loading by the electron is odd sign of that by the positron, but the electron and the positron are captured at the odd-phase of RF and the beam-loading effects of the electron and positron are same sign. Using the Eq. (2) - Eq. (4), the accelerator gradient with beam-loading in injector section is simulated as shown in Fig. 4. The solid red and blue lines show the result by a nominal square RF pulse and by a modulated RF pulse as shown in Fig. 5. In Fig. 4, vertical axis shows V/l . In the simulation, $L = 3$ m, $\omega = 1.3$ GHz, $r = 57$ M Ω , $Q_0 = 10000$, $i = 2.1$ A, and $\beta = 2$. Because beam pulse is injected on the triplet form, input power have to be reduced at the interval between train and train as Fig. 5, and generated peak electric field is blue line in Fig. 4; otherwise accelerator gradient would be not constant as shown red line in Fig. 5. Assuming the ratio of average accelerator gradient to the peak gradient is about 60 % by the transit time factor, the gradient of blue line in Fig. 4 give 18 MV/m average gradient. Maximum input power is about 290 MW which obviously requires a RF pulse compression like SLED system.

SUMMARY

A start-to-end simulation of the ILC electron-driven positron source was performed. Beam-loading in the injector section was simulated and the RF power requirement is possible by a RF pulse compressor system like SLED. These parameters determined by the simulation are even realistic and the system can be constructed without any significant amount of R&Ds. This electron-driven scheme can be a technical backup for the ILC positron source and improves the technical reliability of the ILC project.

Effects of the wake instability including transverse motion in the RF cavity will be evaluate, but it is likely to be manageable due to the large aperture.

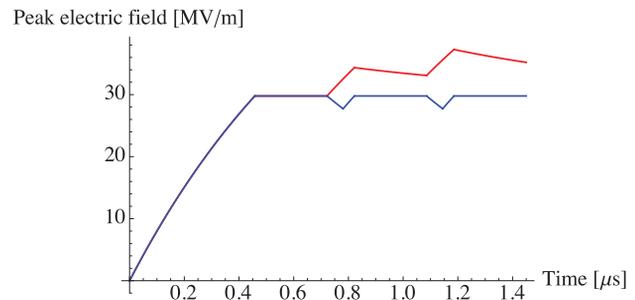


Figure 4: Accelerator peak gradient on L-band standing wave RF cavity. Blue line shows the constant gradient at beam acceleration. This gradient is generated by the input power Fig. 5. The other gradient shown by red line is generated by constant input power to RF cavity.

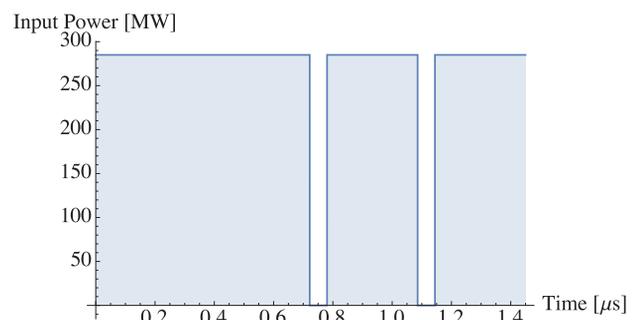


Figure 5: An input power which generates constant gradient at the beam acceleration.

ACKNOWLEDGEMENT

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