ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOPMF077

A DESIGN STUDY OF THE ELECTRON-DRIVEN ILC POSITRON SOURCE INCLUDING BEAM LOADING EFFECT

Hisayasu Nagoshi†, Masao Kuriki, HU/AdSM, Higashi-Hiroshima, Japan
Tohru Takahashi, Hiroshima University, Higashi-Hiroshima, Japan
Kentaro Negishi, Iwate University, Morioka, Iwate, Japan
Tsunehiko Omori, Masanori Satoh, Yuji Seimiya, Junji Urakawa, KEK, Ibaraki, Japan
Yoske Sumitomo, LEBRA, Funabashi, Japan
Shigeru Kashiwagi, Tohoku University, Sendai, Japan

Abstract

The International Linear Collider (ILC) is a next-generation accelerator for high-energy physics to study the Higgs and top sector in the Standard Model, and new physics such as supersymmetry and dark matter. ILC positron source based on Electron-driven method has been proposed as a reliable technical backup. In this article, we report the design study of the positron source based on the off-the-shelf RF components. The positron is generated and accelerated in a multi-bunch format. To compensate the energy variation by the transient beam loading effect, we employ AM (Amplitude Modulation) technique and the results were 16.60 ± 0.14 MV (peak-to-peak) for L-band 2m cavity driven by 22.5 MW power and 25.76 ± 0.19 MV (peak-to-peak) for S-band 2m accelerator driven by 36 MW power with 0.78 A beam loading.

INTRODUCTION

ILC (International Linear Collider) is a linear collider with centre of mass energy of 250 GeV to 1TeV. ILC is expected to contribute to a detail study of Higgs and new physics [1]. In the ILC, positron is generated by Electron-driven (E-driven) method. An enough amount of positrons will be obtained with the E-driven ILC positron source; The positron yield defined as ratio of the number of positrons captured by DR (Damping Ring) acceptance to incident electrons was 2.0[2]. In this estimation, the beam-loading effect was accounted, but not the transient effect. If the energy of each bunch is varied by the transient beam loading effect, the positron yield is also varied resulting the intensity fluctuation of the captured positron. If this is too large, it might cause a problem on the main acceleration and collision. In this article, we study the energy variation caused by the beam loading effect expected in the E-driven ILC positron source and a compensation method.

ELECTRON-DRIVEN ILC POSITRON SOURCE

Schematic drawing of the E-Driven ILC positron source is shown in Fig. 1. 3.0 GeV electrons hit W-Re(26) alloy target to generate positrons through pair creation process. At the downstream of the target, AMD (Adiabatic Matching Device) is placed [3] to suppress the transverse momentum. Thereafter, it is accelerated up to 250 MeV by 36 of 11-cell normal conducting L-Band Standing Wave (SW) cavities [4] surrounded by 0.5 T solenoid field. After a chicane removing electrons from the bunch, the positron booster composed from L-Band and S-Band Traveling Wave (TW) cavities accelerates the positron up to 5 GeV. After the booster, the positrons are injected to DR (Damping Ring) for radiation damping through ECS (Energy Compressor Section) for better phase-space matching.

In ILC, positrons of 3.2 nC per bunch are required at the collision point. In the DR, the required bunch charge is 4.8 nC including 50% margin. The design criteria for the E-driven ILC positron source is to obtain an enough amount of positron in DR acceptance defined in a phase space [3]. The condition in the longitudinal phase-space is 70 mm in z and 1.5% in energy (full width).

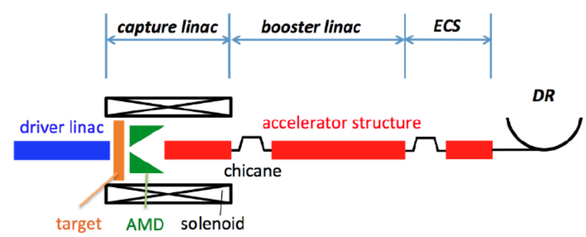

Figure 1: Schematic view of ILC E-driven positron source [3].

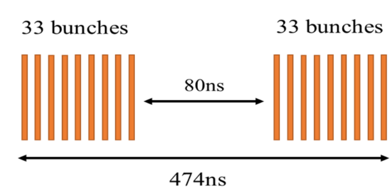

Figure 2: Macro pulse structure of positron source based on Electron-driven. There are two mini-trains in a macro pulse. A mini-train has 33 bunches with 6.15 ns bunch spacing.

On the other hand, the positron is generated and accelerated in a multi-bunch format with gap(s) as shown in Fig. 2. There are two mini-trains consisting of 33 bunches in a macro pulse. The bunch interval is 6.15 ns and the mini-train interval is 80 ns.

The transient beam loading effect varies the energy of each bunch, especially on the train head. In such case, the phase-space distribution for each bunch is shifted and the positron yield will be also varied.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOPMF077

RESULT AND DISCUSSION

The transient beam loading effect should be compensated in the macro-pulse acceleration for ILC E-Driven positron source. Otherwise, we will have a large variation on the positron bunch intensity in DR. The large fluctuation causes a difficulty on the acceleration in the main linac, because the beam loading in a macro-pulse will be varied and we will have a large energy spread. With such beam, the luminosity is much spoiled.

Here, we consider the beam loading compensation with an Amplitude Modulation (AM) of the input RF. The detail of the method is described in Ref.[5]. In this study, acceleration voltage and its variation of TW cavities by assuming the ILC macro-pulse format is evaluated. The table 1. shows the parameters of the TW cavities.

Table 1: Parameter of the TW Cavities of L-Band and S-Band

Parameter	L-Band	S-Band	Unit
Frequency	1300	2600	MHz
Shunt Impedance	47.2	57.8	MΩ/m
Minimum Aperture (2a)	34	20	mm
Filling time	1.28	0.554	µs
Q Value	20000	13600	
Attenuation	0.261	0.333	
Length	2.0	1.956	m
RF power	22.5	36	MW

Figure 3 shows the evolution of accelerating voltage of the S-Band TW cavity with solid and dotted lines (left axis). The solid line shows the voltage where positron bunches are placed. The dashed line shows the input RF power (right axis). The beam current is assumed to be 0.78A. We start the beam acceleration at t = tf. The cavity voltage is rapidly decreased by the transient beam loading. Also, the acceleration voltage increases in the train gap. The average accelerating voltage where positron bunches are placed is 37.65 ± 5.54 MV (peak to peak).

This voltage (energy) variation by the transient beam loading can be compensated perfectly by AM on the input RF [5] in an ideal case. Figure 4 shows the perfect correction on the S-Band TW accelerator. Evolution of the accelerating voltage of the S-band TW cavity with AM is shown with the same man-ner in Fig. 3. The input RF power is increased discontin-uously when we start the acceleration at t = tf to suppress the transient beam loading. The input power has to be low in the train gap to keep the accelerator voltage. The linear modulation on the mini-train is necessary [5]. In this case, the transient beam loading is suppressed per-fectly, i.e. there is no energy variation in the macro pulse. The acceleration voltage is 23.05 ± 0.00 MV. The input RF power is peaked at t=tf and the value is adjusted to 36 MW which is the maximum RF power provided by the source. In the L-Band case, that was 14.42 ± 0.00 MV.

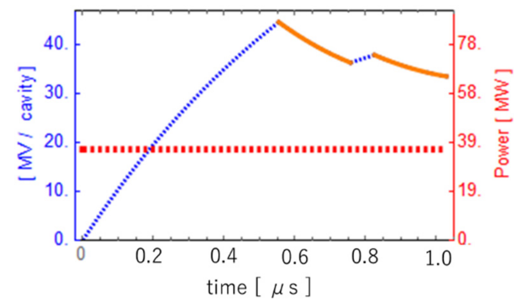

Figure 3: Accelerating voltage and RF power evolution of a S-Band TW accelerator without AM. Dotted and solid lines show the accelerating voltage. The solid line shows the voltage where positron bunches are placed. Red dashed line is the input RF power.

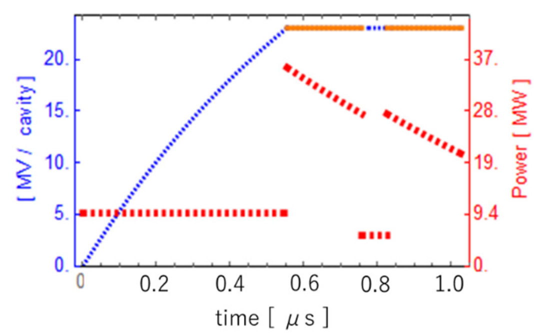

Figure 4: Accelerating voltage and RF power evolution of the S-Band TW accelerator are shown with the same manner in Fig. 3. The RF power is modulated to compen-sate the transient beam loading.

Under this perfect correction condition, the accelerating voltage becomes less than that in Fig. 3 case, 37.65 ± 5.54 MV, because the high peak power is required at t = t_f. To recover the accelerating voltage, we consider omitting the high peak power part at t = t_f. We call this compensa-tion method as quasi-perfect compensation. In such case, the compensation is imperfect and we will have the varia-tion again with a higher voltage. The accelerating volt-age and the variation are in trade-off. Figures 5 and 6 are examples or L-band and S-band cavities, respectively. In Fig. 5, AM has only constant components and no linear component. The voltage is not flat in the mini-train part (solid line) , but the variation is not so large. The peak power is adjusted to 22.5 MW. The average acceleration voltage was 16.60 ± 0.14 MV (peak-to-peak). The spread of the acceleration voltage is about 2% in full width. In S-band case, the input RF power is flattened as shown in Fig. 6 around t = t_f. The peak RF power is adjusted at 36 MW. The results are shown in Fig. 6 with the same man-ner in Fig. 3. The average acceleration voltage was 25.76 ± 0.19 MV (peak-to-

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOPMF077

peak), and the spread of acceleration voltage for each bunch was 1.5% in full width.

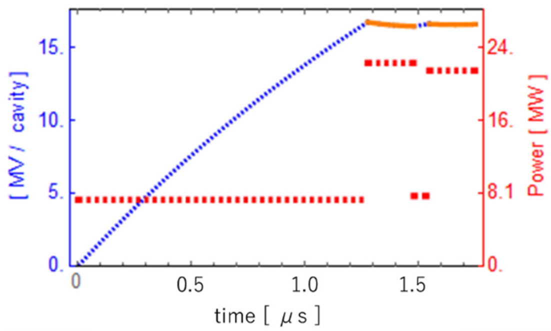

Figure 5: Accelerating voltage and RF power evolution of the L-Band TW accelerator by the quasi-perfect compensation are shown with the same manner in Fig. 3. The average accelerating voltage where positron bunches are placed is 16.60 ± 0.14 MV (peak-to-peak).

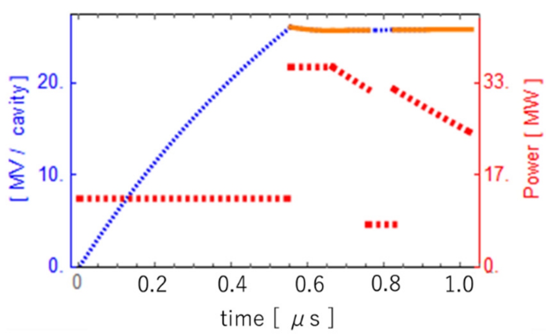

Figure 6: Accelerating voltage and RF power evolution of the S-Band TW accelerator by the quasi-perfect compensation are shown with the same manner in Fig. 3. The average accelerating voltage where positron bunches are placed is 25.76 ± 0.19 MV, (peak-to-peak).

The difference between the optimum solution for L-band and S-band comes from the filling time. Because the L-band cavity has a long filling time, 1.28 us, AM with the constant components is very effective. In contrast, the filling time of the S-band cavity is 0.554 us and the variation becomes too large if we employ only the constant components.

Based on the accelerator performance evaluated with the quasi-perfect compensation for the transient beam loading effect, we designed the booster section. The beam optics has been designed by Seimiya based on a basic FODO lattice[3]. The number of lattice is adjusted for each section giving a same (or close) acceleration energy. Table 2 shows the result. 4Q+1L means that a lattice is composed from 4 quadrupoles and 1 L-band TW cavity and so on. In total, there are 144 TW L-Band cavities and 104 TW S-band cavities.

Table 2: The lattice configuration and the number of cells for each section. 4Q+1L means that a lattice is composed from 4 quadrupoles and 1 L-band TW cavity and so on.

Latice	number of cell
4Q + 1L	14
4Q + 2L	29
4Q + 4L	18
4Q + 4S	26

The bunch energy after the booster is evaluated based on the accelerating voltage calculated in Fig. 5 and 6. The results are shown in Fig. 7. The horizontal axis is time in the macro-pulse, corresponding to the bunch order. The energy of the first bunch is the highest and that at the last bunch of the first mini-train is the least. The average is 5.31 ± 0.04 GeV (peak-to-peak) which corre-sponds to 1.4% (full width).

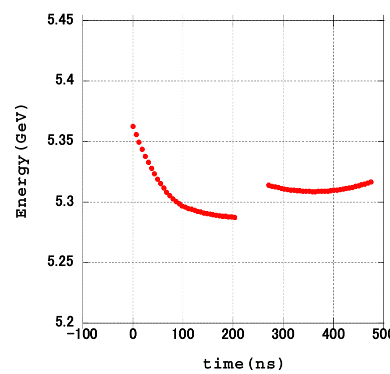

Figure 7: Expected energy after the booster for the macro-pulse. The horizontal axis is the time in the macro-pulse.

SUMMARY

As a design study of E-Driven ILC positron source, we examined the beam loading compensation for the multi-bunch acceleration in the positron booster. By AM technique, the energy variation of the positron bunches in the booster can be compensated perfectly. In the perfect compensation, a high peak power is required at t = tf. and a relatively low acceleration field has to be accepted. With the quasi-perfect compensation, the accelerating field is recovered paying an energy variation. The results were 16.60 ± 0.14 MV (peak-to-peak) for L-band 2m cavity driven by 22.5 MW power and 25.76 ± 0.19 MV (peak-to-peak) for S-band 2m ac-celerator driven by 36 MW power with 0.78 A beam load-ing. We are designed the booster based on the accelerator performance. The energy after the booster is expected to be 5.31 ± 0.04 GeV (peak-to-peak) for the macro-pulse, 1.4 % in full width. Please note that this 1.4% should not be compared to DR acceptance in energy, 1.5%. ECS suppresses the energy variation and the bunch after ECS should be examined with DR acceptance. An impact of the 1.4 % energy variation after the booster is expected

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOPMF077

to be small, but it will be evaluated simulations as a next issue.

REFERENCES

[1] ILC *Technical Design Report*, KEK-Report 2013-1, 2013.

[2] M. Kuriki, “A Simulation Study of E-driven ILC Positron Source”, LCWS 2017 at Strasbourg, 2017.

[3] Y. Seimiya, “Positron capture simulation for the ILC electron-driven positron source”, PTEP(2015) 103G01, 2015.

[4] J. W. Wang et al., “Positron Injector Accelerator and RF System for the ILC”, SLAC-PUB-12412, 2007.

[5] M. Kuriki, “Energy Spread Compensation in Arbitrary Format Multi-Bunch Acceleration With Standing Wave and Traveling Wave Accelerators”, presented at the 9th Int. Particle Accelerator Conf. (IPAC’18), Vancouver, Canada, Apr-May 2018, paper MOPMF076.