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THE EFFECT OF ENERGY FLUCTUATION ON THE MULTI-BUNCH ACCELERATION IN E-DRIVEN ILC POSITRON SOURCE

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Abstract

E-Driven method is a technical backup for positron source for ILC. In the positron source, the positron is generated and accelerated in a multi-bunch format with gaps in a macro-pulse. We employ AM (Amplitude Modulation) to suppress the transient beam-loading, but a small fluctuation is still expected, depending on the compensation accuracy. In this article, the positron yield which is ratio of numbers of positrons over electrons, is evaluated as a function of the compensation accuracy. With this result and the detail investigation of the beam loading compensation accuracy by AM, the positron yield of E-Driven Positron source for ILC is evaluated.

INTRODUCTION

ILC (International Linear Collider) [1] is an e+e- linear collider with CME from 250 to 1000 GeV. It would be constructed in Iwate, Japan, as the main project of High energy physics. In the E-driven ILC positron source, the positron is generated in a macro-pulse with 6.15 ns bunch spacing [2]. 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 a sufficient 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).

Because the macro pulse is a copy of a part of DR (Damping Ring) fill pattern, there is a gap as shown in Fig. 2. This is an example and number of gaps depends on DR fill pattern. Seimiya performed a start-to-end simulation of the E-Driven ILC positron source without the beam loading effect [3].

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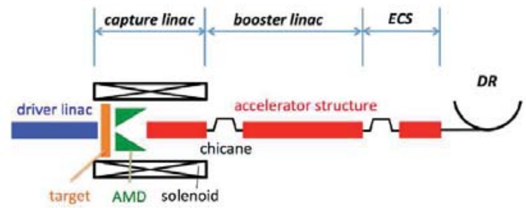

Figure 1: Schematic view of ILC E-driven Positron source.

Kuriki perform the simulation with the beam loading effect, but it is only for the injector part (up to 250 MeV) [4]. To accelerate the beam in such format, the transient beam loading effect which varies the accelerating field at the macro pulse and every mini-train heads, has to be compensated.

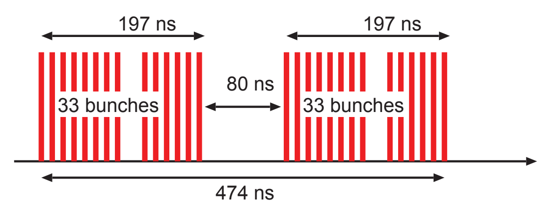

Figure 2: An example of macro-pulse structure in E-Driven ILC positron source. The macro pulse is composed from two mini-trains of 33 bunches with 6.15 ns bunch spacing. There is a gap of 80 ns.

M. Kuriki [5] shows that the energy variation by the beam loading with this beam format can be compensated by controlling timing and RF envelope in standing wave accelerator. H. Nagoshi et al. [6] shows that amplitude modulation [5] is effective to compensate the beam loading in travelling wave accelerator. The compensation can be perfect, but it requires a high peak RF input. The compensation have some imperfection if we limit the peak RF power [6] and an energy variation in pulse due to this imperfection is expected. In this article, we evaluate the yield variation of the positron source by the energy variation in pulse.

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

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Table 1: L-Band and S-Band TW Cavity Parameters

Parameter	L-Band	S-Band	Unit
Frequency	1300	2600	MHz
Shunt Impedance	47.2	57.8	MΩ/m
Aperture (2a)	34	20	mm
Filling time	1.28	0.554	μs
Q Value	20000	13600	none
Attenuation	0.261	0.333	none
Length	2.0	1.956	m
RF power	22.5	36	MW

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. Table 1 shows the parameters of the TW cavities.

According to Ref. [6], if we apply a square RF pulse to the S-band structure, the average accelerating voltage for positron bunches is 37.65 ± 5.54 MV. This voltage (energy) variation by the transient beam loading can be compensated perfectly by AM on the input RF [5] in an ideal case. The input RF power is increased discontinuously when we start the acceleration at $t = t_f$ 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 perfectly, 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 $t = t_f$ 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.

Under this perfect correction condition, the accelerating voltage becomes less than that in the square RF pulse 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 compensation method as quasi-perfect compensation. In such case, the compensation is imperfect and we will have the variation again with a higher voltage. The accelerating voltage and the variation are in trade-off. Figures 3 and 4 are examples of L-band and S-band cavities, respectively.

In Fig. 3, 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 = tf. The peak RF power is adjusted at 36 MW. The results are shown in Fig. 4 with the same manner in Fig. 3. The average acceleration voltage was 25.76 ± 0.19 MV (peak-to-peak), and the spread of acceleration voltage for each bunch was 1.5% in full width.

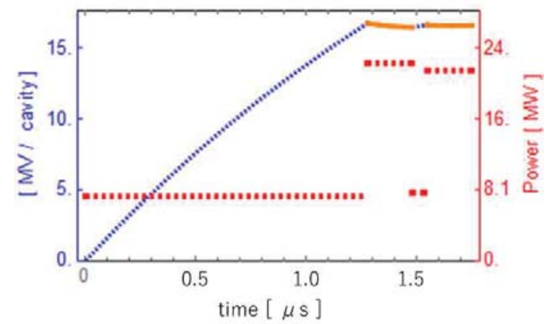

Figure 3: Accelerating voltage and RF power evolution of the L-Band TW accelerator by the quasi-perfect compensation are shown with the same manner in Fig. 3. The average acceleration voltage was 16.60 ± 0.14 MV (peak-to-peak).

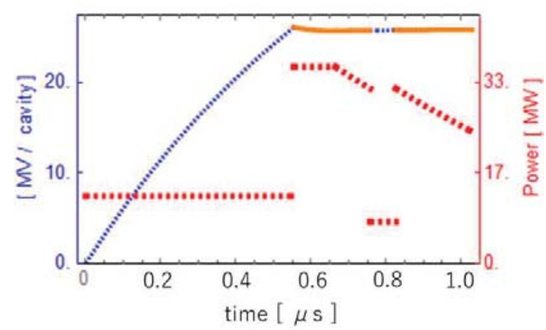

Figure 4: Accelerating voltage and RF power evolution of the S-Band TW accelerator by the quasi-perfect compensation are shown with the same manner in Fig. 3. The average acceleration voltage was 25.76 ± 0.19 MV, (peak-to-peak).

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.

The bunch energy after the booster is evaluated based on the accelerating voltage calculated in Figures 3 and 4. The results are shown in Fig. 5. The horizontal axis is time in the macro-pulse, corresponding to the bunch order. The energy

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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.

Lattice	No. Cells
4Q + 1L	14
4Q + 2L	29
4Q + 4L	18
4Q + 4S	26

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 corresponds to 1.4% (full width). This enery variation is larger than the energy acceptance (dynamic aperture) of DR, but it should not be compared directly to the acceptance. ECS suppress the energy spread greatly down to 0.1 %.

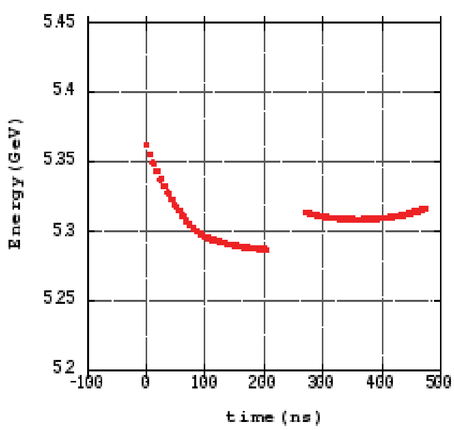

Figure 5: Expected energy after the booster for the macro-pulse. The horizontal axis is time in the macro-pulse.

Figure 6 shows the positron yield variation in a pulse. t = 0 corresponds to the pulse head, and the area between t = 205ns and t = 270ns corresponds to the train gap. The variation is larger for the first train, because of the larger energy variation. For the whole pulse, the positron yield variation is 1.91 - 2.03, which corresponds to 6% in full width.

This intensity variation is not large, but the effect should be carefully investigated. Potential problem is acceleration in main linac. In the main linac, super-conducting accelerator is employed. In the super-conducting accelerator, accelerating voltage variation is caused by the beam current variations. In fact, the variation is suppressed by a feed-back control to the input RF power. The highest intensity variation capable by the RF feed-back depends on the reserve capacity.

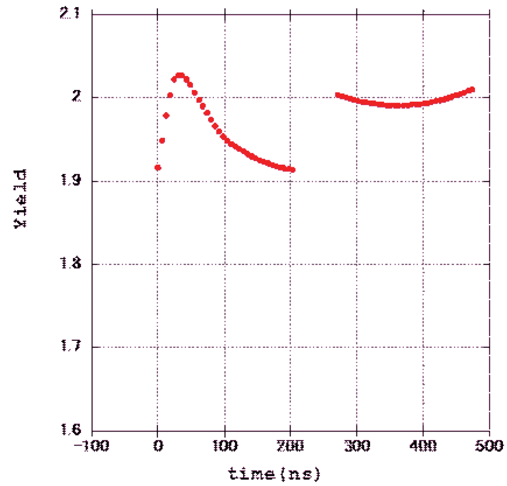

Figure 6: Positron yield variation in a pulse.

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 accelerator driven by 36 MW power with 0.78 A beam loading. 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. It cause the variation of the positron yield 1.91 -2.03, 6% in full width. This intensity variation determine the reserve capacity of the RF feed-back in the main linac.

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