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EFFECT OF INITIAL PARAMETERS ON THE SUPER FLAT BEAM GENERATION WITH THE PHASE-SPACE ROTATION FOR LINEAR COLLIDERS

M. Kuriki*, R. Tamura, HU/AdSM, Higashi-Hiroshima, Japan,
J. Power, ANL, Argonne, Illinois,
H. Hayano, X. Jin, T. Konomi, Y. Seimiya, N. Yamamoto, KEK, Tsukuba, Japan,
P. Piot, Northern Illinois University, DeKalb, Illinois,
M. Washio, RISE, Tokyo, Japan, K. Sakaue. U. of Tokyo, Tokyo, Japan,
S. Kashiwagi, Tohoku University, Sendai, Japan

Abstract

Linear collider is a concept to realize e+e- collision beyond the limitation of the ring colliders by the synchrotron radiation energy loss. To obtain an enough luminosity, the beam is focused down to nano-meter size with a high aspect ratio. This super flat beam is useful to improve the luminosity and to compensate the beam-beam effect, eg. Beamstrahlung. In a conventional design, the super-flat beam is produced by radiation damping in a storage ring. We propose to produce this super-flat beam with phase-space rotation techniques. We employ both Round to Flat Beam Transformation and Transverse to Longitudinal Emittance eXchange, the super flat beam can be generated by controlling the space-charge effect which spoiled the performance. We present the RFBT performance with respect to the initial conditions, i.e. beam size, initial emittance, solenoid field (strength and profile), etc.

INTRODUCTION

Electron Positron Collider is the only way to realize annihilation of elementary particles with controlled conditions with the current technology. Because there has been no any significant evidence of Super-symmetry in LHC experiments, the significance of detail studies of Higgs boson and searching inconsistency in the standard model with electron positron collider is maximized. ILC (International Linear Collider) [1] is an e+e- linear collider based on superconducting accelerator with CME from 250 to 1000 GeV. It would be constructed in Iwate, Japan, as the main project of High energy physics.

Luminosity L of linear colliders is

$$L = \frac{f n_b N^2}{4\pi\sigma_x\sigma_y}, \qquad (1)$$

where f is repetition of pulse, n_b is number of bunches in a pulse, N is number of particles in a bunch, $\sigma_{x,y}$ is transverse beam size. In the linear collider, the beam after the collision is dumped. If we employ a large current beam in linear colliders as same as in ring colliders, the required wall plug power is huge and such machine is unrealistic. One way to enhance the luminosity is minimize $\sigma_{x,y}$, but it causes a large energy spread by Beamstrahlung which is proportional to $(\sigma_x + \sigma_y)^{-2}$. A practical way to enhance the luminosity and suppress Beamstrahlung simultaneously is squeezing the beam in one of the transverse direction, e.g. $\sigma_x \gg \sigma_y$. For ILC, The beam size at IP is 640 nm in horizontal direction and 5.7 nm in vertical direction. Emittances are 10 and 0.04 mm.mrad in horizontal and vertical directions, respectively [1]. This asymmetric emittance beam is made by radiation damping in a storage ring in the current design. We propose to generate the flat beam for ILC only with the injector by employing the emittance exchange technique.

There are two methods as the phase-space rotation for the re-partitioning. One is RFBT (Round to Flat Beam Transformation) [2] generating the flat beam from an angular-momentum dominated beam produced by beam emission in a solenoid field. Another is TLEX (Transverse to Longitudinal Exmittance eXchange) exchanging the phase-spaces between longitudinal and transverse directions by dipole mode cavity in a dispersive beam line [3]. These two techniques are experimentally demonstrated by P. Piot et al. [4] for RFBT and Y-E Sun et al. [5] for TLEX. The flat beam generation with RFBT and TLEX are explained in Ref. [6] for more detail.

In the ILC current design, the emittance at IP are 10 mm.mrad for horizontal direction, 0.04 mm.mrad for vertical direction, and 8.4×10^5 mm.mrad for longitudinal direction. This beam is made up with radiation damping in 3 km DR in the current design [1]. We propose the flat beam generation with the emittance exchange techniques, RFBT and TLEX as shown in Figure 1. The emittance budget is summarized

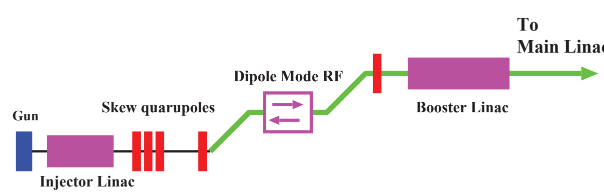

Figure 1: The injector design employing the emittance exchange techniques, RFBT and TLEX.

In Table 1 the first row is required emittance at IP for ILC. The second row is emittance at Gun when we employ only RFBT. In RFBT, the product of ε_x and ε_y is conserved. To make 10 mm.mrad and 0.04 mm.mrad with RFBT, the emittance from Gun should be 0.6 mm.mrad. This small emittance cause several problems, e.g. emittanc growth by

* mkuriki@hiroshima-u.ac.jp

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Table 1: Emittance Budget for ILC at IP (TDR), Case 1 (Only RFBT, Gun), Case 2 (RFBT and TLEX, Gun), and Case 2 (RFBT and TLEX, IP). Emittance is in mm.mrad

Design	ε_x	ε_y	ε_z
ILC at IP (TDR)	10	0.04	2.5×10^5
Case 1 (RFBT, gun)	0.6	0.6	2.5×10^5
Case 2 (RFBT+TLEX, gun)	45	45	10
Case 2 (RFBT+TLEX, IP)	10	0.04	5.1×10^4

Table 2: RFBT Simulation Parameter

Paramter	value	unit
RMS bunch length	3	ps
Solenoid field on Cathode	0.0824	T
RMS beam size	0.8	mm
Gun peak field	35	MV/m
Cavity peak field	25	MV/m
Quadrupole length	0.102	m

space charge. The third row shows the emittance at gun when we employ RFBT and TLEX. If we employ RFBT and TLEX, the product of three emittance (x, y, and z) can be conserved and therefore, ε_x and ε_y can be large to avoid the problem at the gun emission and the space charge emittance growth. The fourth row shows the expected emittance with the same parameter at IP. ε_x and ε_y are compatible to the ILC requirement at IP. ε_z is still less than the requirement.

In the following sections, simluation studis for RFBT and TLEX to realize the ILC compatible beam are presented.

RFBT PERFORMANCE

In this section, the result of RFBT simulation is presented. The simulation was performed with ELEGANT code. RFBT consists from the electron gun with solenoid field, booster cavity, and skew quadrupoles as shown in the left side of figure 1. The beam is generated by 1.3 GHz RF gun with a solenoid field. The beam is then accelerated by 1.3 GHz super-conducting acclerator. Three skew quadrupoles are placed to remove the $x-y$ correlation made by the solenoid field. The simulation parameter is summarized in Table 2. The space charge effect is not included. The expected emittace by theory with these parameters is

$$\varepsilon_n^+ = 28.71mm.mrad, \quad \varepsilon_n^- = 0.023mm.mrad, \qquad (2)$$

giving 1250 emittance ratio.

Figure 2 shows emittances after RFBT as a function of solenoid field strength on cathode. Other parameters are fixed. ε_{T+} and ε_{S+} (left axis) are larger emittances obtained by theory and simulation, respectively. ε_{T-} and ε_{S-} (right axis) are smaller emittances obtained by theory and simulation, respectively. The larger emittance by theory and simulation are consistent, but the smaller emittance by theory and simulation are inconsistent, especially on larger solenoid field. The reason is the chromatic effect on the skew quadrupole.

Figure 3 shows the emittances with the same definition as those in figure2 as a function of the initial beam size.

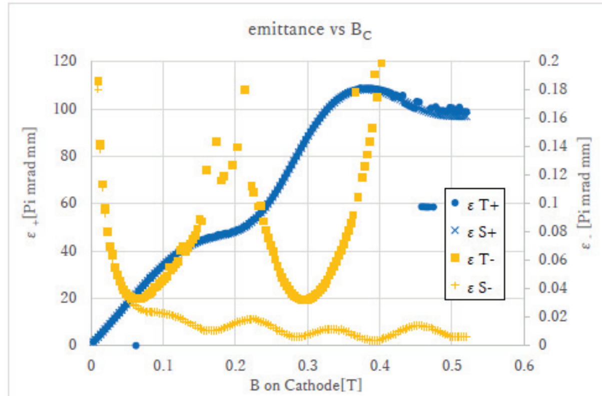

Figure 2: Emittances after RFBT as a function of solenoid field strength on cathode are shown. ε_{T+} and ε_{S+} (left axis) are larger emittances obtained by theory and simulation, respectively. ε_{T-} and ε_{S-} (right axis) are smaller emittances obtained by theory and simulation, respectively.

The larger emittances by theory and simulation show good agreement, but the smaller emittances by theory and simulation show discrepancy which increases monotonically. The reason is the chromaticity on the quadrupoles.

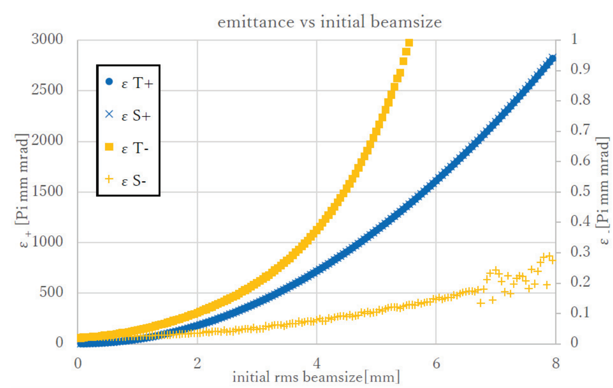

Figure 3: Emittances after RFBT as a function of initial beam size. ε_{T+} and ε_{S+} (left axis) are larger emittances obtained by theory and simulation, respectively. ε_{T-} and ε_{S-} (right axis) are smaller emittances obtained by theory and simulation, respectively.

According to these results, the emittance growth was observed on the smaller emittance at the larger solenoid field and larger beam size. If an appropriate parameter is chosen, several hundered emittance ratio can be obtained.

TLEX PERFORMANCE

TLEX beam line consists from two dogleg sections and one dipole mode cavity as shown in the middle of figure 1. The simulation was performed with ELEGANT code without space charge effect and CSR effect. The paremeters are summarized in Table 3. The beam parameter for x and z are same.

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Table 3: TLEX simulation parameters.

Paramter	value	unit
Dipole length	0.2	m
Distance between dipoles	1.0	m
Distance between magnet and cavity	0.3	m
Cavity length	0.3	m
Cavity field	8.0	MV
Bending angle	20	deg.
Dispersion	-0.46	m
Momentum compaction	0.16	m
Beam energy	100	MeV
Beam rms size (x, z)	1	mm
Emittance (x,z)	197	mm.rad

To evaluate the accuracy of the emittance exchange by TLEX, the emittance ratio R is defined as

$$R \equiv \frac{\varepsilon_{x0}\varepsilon_{z0}}{\varepsilon_{x1}\varepsilon_{z1}}, \quad (3)$$

where ε_{x0}, ε_{z0}, ε_{x1}, and ε_{z1} are initial x emittance, initial z emittance, final x emittance, and final z emittance, respectively. If TLEX works as expected, $\varepsilon_{x1} = \varepsilon_{z0}$ and $\varepsilon_{z1} = \varepsilon_{x0}$ giving $R = 1$.

R is influenced by thick-lens effect of dipole mode cavity as

$$R = \sqrt{(1 + \lambda^2\rho_0)(1 + \lambda^2/\rho_0)}, \quad (4)$$

where $\rho_0 \equiv \varepsilon_{x0}/\varepsilon_{z0}$ and

$$\lambda^2 \equiv \frac{L_c^2(1 + \alpha_{x0}^2)(\xi^2 + (\xi\alpha_{z0} - 2\beta_{z0})^2}{64\eta^2\beta_{x0}\beta_{z0}}, \quad (5)$$

where $\alpha_{x0,z0}$ and $\beta_{x0,z0}$ are initial Twiss parameter for x and z, η and ξ are dispersion and momentum compaction of Dogleg section.

Figure 4 shows R as a function of the initial beam size in x. Poinst show the simulation results and the solid line shows the theoretical curve by Eq. (4). They are in good agreement. Figure 5 shows R as a function of the initial beam size in z. Poinst show the simulation results and the solid line shows the theoretical curve by Eq. (4). They are in good agreement, too.

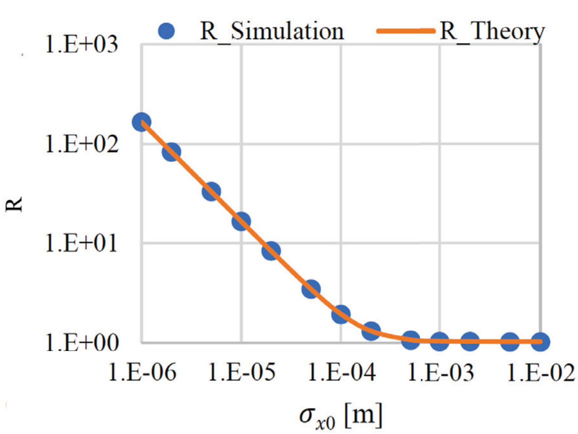

Figure 4: R as a fucntion of the initial beam size in x. Points show the simulation results and the solid curve shows the theoretical curve by Eq. (4).

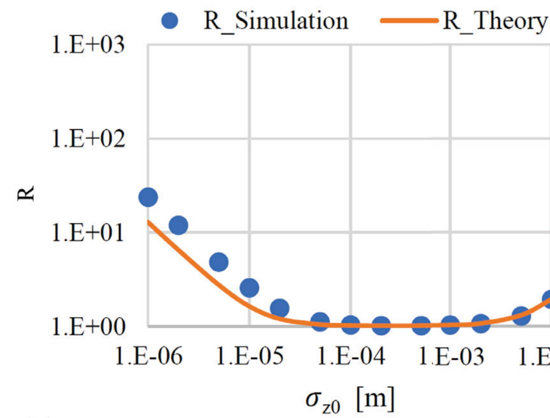

Figure 5: R as a function of the initial beam size in z. Points show the simulation results and the solid curve shows the theoretical curve by Eq. (4).

According to these results, TLEX works well as expected for $\sigma_{x0} > 1.0 \times 10^{-4}$ and $1.0 \times 10^{-4} < \sigma_{z0} < 1.0 \times 10^{-3}$.

SUMMARY

Simulation study for RFBT and TLEX to obtain ILC compatible beam with the emittance exchange technique was presented. RFBT and TLEX are capable to generate the ILC compatible beam, if appropriate beam parameters are chosen. Chromatic effect of quadrupole is dominant for emittance growth in RFBT. To suppress the effect, quadrupole strength should be optimized as low as possible. Thick lens effect of dipole mode cavty is dominant for emittance growth in TLEX. In addition to the initial beam size, the Twiss parameter should be optimized. The space charge effect is not included in these studies. The space charge effect might be significant in the lower energy region. The effect can be supprésed by expanding beam size at cathode, but we have to confirm the condition is compatible to our purpose.

ACKNOWLEDGEMENTS

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