PRODUCTION OF FEMTOSECOND ELECTRON PULSE USING ALPHA MAGNET TOGETHER WITH OFF-CREST ACCELERATION FOR GENERATION OF COHERENT THz RADIATION*

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Abstract

We have studied production of the very short-bunch electron beam to generate intense coherent THz radiation. The coherent synchrotron radiation spectrum is proportional to the bunch form factor, and in order to obtain large form factor enough to generated intense coherent THz radiation, very short bunches (< 100 fs) must be produced. The beam from the thermionic RF-gun is introduced into the bunch compression system consist of an alpha magnet and a linac. The alpha magnet is used in order to rotate the longitudinal phase space. The bunch compression is done in the linac employing velocity bunching.

The beam is injected on near the zero-cross phase of the RF field in the linac, and then the beam phase slips toward the crest. The particle distribution in the longitudinal phase space and the beam phase with respect to RF field at the entrance of the linac are optimized so as to produce the minimum bunch length. In addition to space charge effect, the transfer matrix of the alpha magnet has coupling terms in the 6-dimensional phase space, analytical evaluation of the beam dynamics is very difficult. Then, we used a numerical simulation based on the GPT code [1]. Consequently the bunch length of 60 fs has been obtained for a bunch charge of 20 pC. We discuss the bunch compression scheme in this article.

INTRODUCTION

A facility t-ACTS (test Accelerator as Coherent THz Source) has been developed at Tohoku University [2]. Figure 1 shows the t-ACTS that consists of an injector linac, an isochronous ring and an undulator. The coherent terahertz radiation is emitted from circulating electron bunches in the isochronous ring [3]. To produce the coherent THz radiation, a bunch length less than 100 fs is required. The bunch compression will be performed by the chicane for this source. The undulator will be used for a pre-bunched free electron laser [4] or a narrow-band coherent synchrotron radiation source (CSR) [5]. In this paper, we discuss the detail of production of very short electron bunches by using the small system consist of an RF-Gun, an alpha magnet and a 3 m-long S-band linac. The parameter of coherent THz source is shown in Table 1.

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Table 1: Parameters of coherent THz source [5]

Beam	
Energy	17 MeV
Bunch Charge	20 pC
Bunch length	< 100 fs (rms)
Normalized emittance	< 10 π mm mrad
Undulator	
Period length	0.1 m
Number of periods	25
Gap	54 - 68 mm
Peak magnetic field	0.39 - 0.26 T

GENERATION OF VERY SHORT BUNCH

ITC-RF Gun

The thermonic RF gun has two independent cavity cells. To obtain low emittance beam and high current density, the single crystal LaB_6 cathode with a diameter of 1.75 mm has been chosen. Because input power of two cells and relative phase between two cells $\Delta\theta$ could be varied, the longitudinal beam phase space can be controlled, and then it is named the ITC (Independently

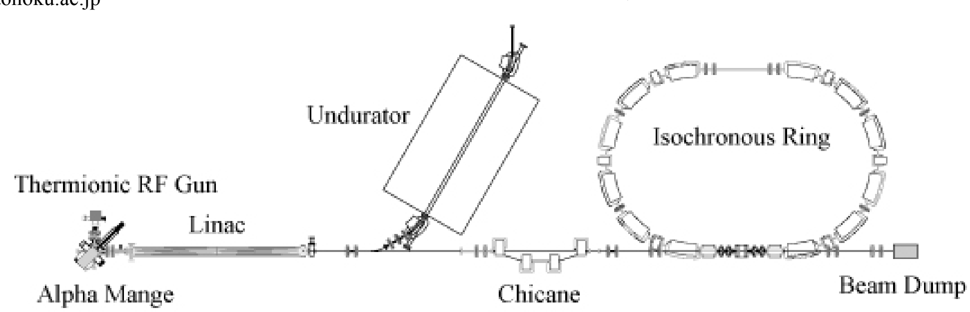

Figure 1: Schematic design of Test Accelerator-based Coherent THz Source (t-ACTS).

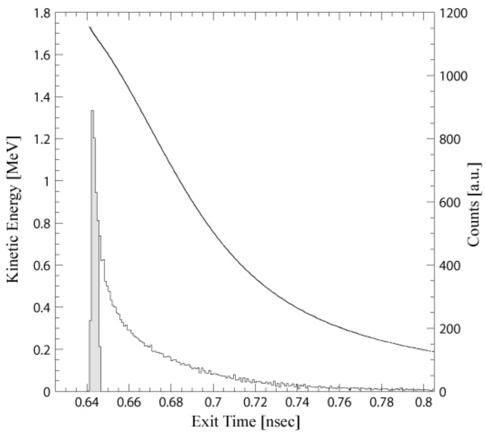

Figure 2: Particle distribution in the longitudinal phase space at the exit of the ITC-RF gun. The phase space was calculated by GPT code. The histogram represents the number of particles in each timing bins. The hatched area contains charge of 20 pC.

Tunable Cells) RF gun [6]. Figure 2 shows the longitudinal phase space distribution of the beam at the gun exit. The distribution was calculated by GPT code for (E_1, E_2) = (25, 70) MV/m and $\Delta\theta = \pi + 24°$, where E_1 and E_2 denote the peak electric fields at the cathode surface and the middle of the second cell, respectively. In the simulations, 68,000 paricles were generated in an RF cycle and an SC3D routine for space charge effect was employed. Particles are distributed in the energy range of 1.72 to 0 MeV, and concentrate in the bunch head. The low energy tail of the beam is removed by the slit in the alpha magnet. In Figure 2, the hatched area corresponds to the total charge of 20 pC.

Alpha Magnet

The alpha magnet rotates the longitudinal phase space of the beam for the bunch compression in the linac structure to generate sub-picosecond electron bunches. This system has been already reported from the Stanford SUNCHINE facility and the Plasma and Beam Physics Research Facility at Chang-Mai University [7,8]. The system does not compress the bunch in the alpha magnet itself.

Bunch Compression in Linac

The bunch compression is performed in the linac structure. To understand bunch compression scheme easily, we performed a simulation without space charge effect. The beam is injected near the zero-cross phase of the RF field in the linac. The relative injection phase with respect to the crest is optimized so as to minimize the bunch length. Figure 3 shows the evolution of the particle distribution in the longitudinal phase space for +77° off-crest acceleration at the linac entrance. The backward particles in the bunch are much more accelerated than the forward particles, and then they catch up the forward particles. In the bunch head, the lowest energy particle slips toward the crest quickly.

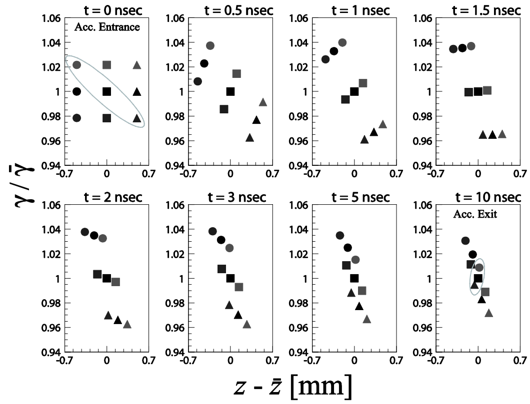

Figure 3: Evolution of the longitudinal phase space for +77° off-crest acceleration. The calculation is performed without the space charge effect. The $\bar{z}$ is position of the center of the bunch.

Consequently the highest energy particle becomes the lowest energy particle at the linac exit. Therefore, phase space distribution surrounded by ellipse line gives short and lower energy spread bunch.

The longitudinal phase space distribution at the linac entrance can be controlled by the field gradient of the alpha magnet, and the field gradient of 3 T/m has been chosen in this study. Figure 4 shows longitudinal phase space distributions calculated by GPT with the space charge effect. The compressed bunch length was obtained to be 63 fs (rms). The profile of the bunch length and velocity along the z-axis are shown in Figure 5. A clear correlation between the bunch length and its velocity can be seen.

The horizontal and vertical beam sizes are also shown in Figure 5. The field gradient and the position of quadruple magnets are optimized by iterative method. The beam spread is caused by the transverse component

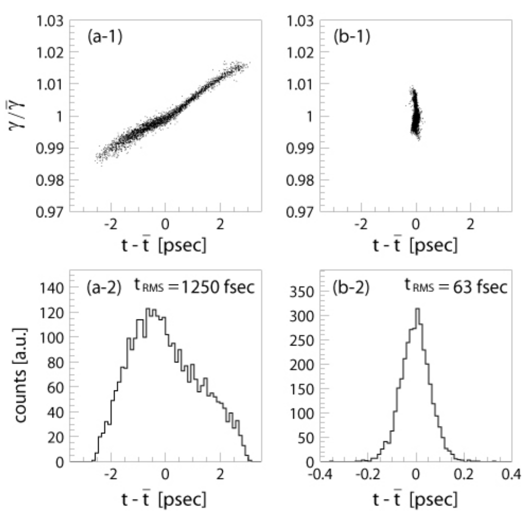

Figure 4: Particle distribution in the longitudinal phase space at the linac entrance (a-1) and exit (b-1). Lower (a-2) and (b-2) are figures are time distribution of (a-1) and (b-1). The $\bar{\gamma}$ at the linac entrance and exit is 4.3 (1.7 MeV) and 34.9 (17.3 MeV), respectively.

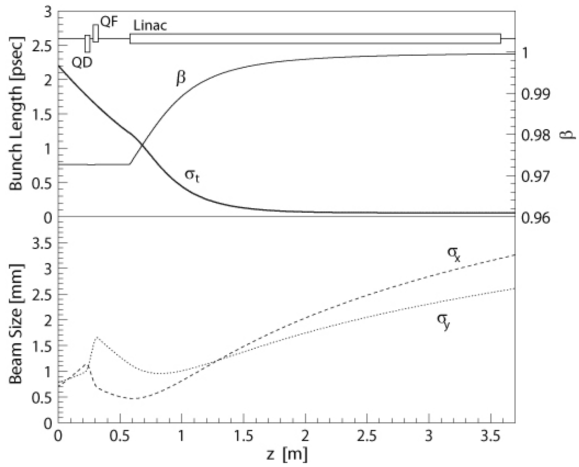

Figure 5: Upper: beam size (left axis) and velocity of the bunch (right axis). Lower: The dashed and dotted lines are beam size in the horizontal (σ_x) and vertical (σ_y), respectively.

of the accelerating field that is enhanced due to off-crest acceleration. However, the smaller beam size less than 3 mm is obtained throughout the linac. At the linac exit, the normalized emittances for both the horizontal and the vertical are 5.0 and 2.1 π mm mrad, respectively. Then, the initial target value less than 10 π mm mrad are achieved.

We have not optimized the beam distribution in the longitudinal phase space at gun exit and the field gradient of the alpha magnet as well. The more precise analysis is desired. Moreover, specific characteristics of CSR from the very short electron bunches in our system should be studied.

SUMMARY

We have studied production of the very short electron bunch (< 100 fs), which is required to generate intense coherent radiation in the THz region. We have shown that the length of 63 fs electron bunch can be produced by using a small accelerator system which consists of ITC-RF gun and an alpha magnet and a linac. The compression is performed in the linac employing velocity bunching with the off-crest acceleration, in which the beam size of about 3 mm, and the normalized emittance of 5.0 (horizontal) and 2.1 (vertical) π mm mrad are obtained from the simulation study using GPT code.

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