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Proof-of-Principle Experiment of Velocity Bunching for Ultra-short Electron Pulse Production

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Abstract

An accelerator test facility, t-ACTS, established at Research Center for Electron Photon Science, Tohoku University, equips an injector consisted with a thermionic RF gun together with an energy filter and a 3 m traveling wave accelerating structure. A long-period undulator has been also installed for provide THz superradiance. Velocity bunching scheme proposed by Serafini and Ferrario is employed for ultra-short electron pulses production. A non-relativistic electron bunch, which is slightly slower than the velocity of light, is injected into the accelerating structure, and then the longitudinal phase space of the bunch is being rotated during acceleration. According to a numerical simulation, ~ 50 fs bunch can be produced by using the t-ACTS accelerator configuration. Proof-of-principle experiment of velocity bunching has been carried out by observing sub-picosecond electron pulse using a streak camera. We have succeeded in producing a sub-picosecond electron pulse in the t-ACTS. The details of the experiment for ultra-short electron pulse are described in this paper.

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Keywords: short electron beam, coherent radiation, terahertz, Superradiance

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1. Introduction

Intense coherent THz source is a powerful tool for many scientific fields such as biophysics and molecular science. The t-ACTS (test accelerator as coherent terahertz source) has been developed towards intense THz source at Research Center for Electron Photon Science, Tohoku University [1]-[2]. Superradiance (or coherent radiation)

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can be emitted from the electron beam when its form-factor is sufficiently large. Assuming Gaussian shape for the electron longitudinal distribution, the longitudinal form factor of 0.7 is obtained for which an optical wavelength is tenth of the bunch length. Since 1 THz radiation's wavelength (λ) is 300 μm and the intrinsic photon emittance is $\lambda/4\pi$ (24 μrad), the bunch length less than 30 μm (100 fs) and a normalized transverse emittance less than $24\beta\gamma$ μrad are required for superradiance.

The t-ACTS accelerator system consists of a compact linac with a thermionic RF-gun and an undulator [3]. A narrow band THz coherent radiation is obtained from the undulator has been considered [4]. The t-ACTS project employs the velocity bunching scheme [5] in its linear accelerator to produce the ultra-short electron bunches [6]. The injector adopted a thermionic cathode RF gun which was deliberately chosen for stable multi-bunch operation and for cost efficiency. The thermionic RF gun consists of two independent cavities has been developed, which is capable of manipulating the beam longitudinal phase space. The longitudinal phase space distribution of a beam entering an accelerating structure is optimized by changing the RF gun parameters to produced ultra-short electron pulse.

At present, the t-ACTS completed the construction of the linear accelerator part as shown in Fig. 1 and the facility was approved for the regulation of radiation safety on December 19th 2013. Proof-of-principle experiment of velocity bunching has been performed by measuring a pulse length of electron beam observing OTR by a streak camera. A relation between the compressed electron pulse length and an injection phase of beam to an accelerating structure was investigated. The preliminary results of the experiments are described in this paper.

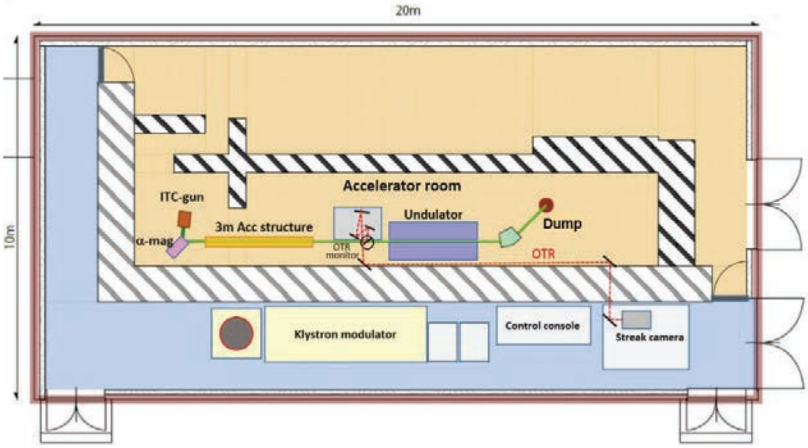

Fig. 1 Accelerator test facility (t-ACTS).

2. Ultra-short electron pulse production

2.1. Velocity bunching

In the velocity bunching, the non-relativistic electron bunch is injected into zero-cross phase ($\psi = 0$) of an accelerating structure to obtain the minimum pulse length. Since the phase velocity in the accelerating structure is equal to the speed of light, the non-relativistic electron bunch slips backward to the direction of crest phase and they will be accelerated and rotated in longitudinal phase space as shown in Fig. 2. Injected electron bunch moves along the equi-potential line in the longitudinal phase space. Ideally, the compression factor becomes maximum when the injected electron distribution is exactly on the same equi-potential line. Since nonlinearity of the equi-potential line at higher injection energy is stronger, a lower energy beam with mono-energy electron distribution in the longitudinal phase space is helpful to relieve the nonlinear effect (Fig. 2). The pulse length after acceleration strongly depends on the longitudinal phase space distribution of injection beam into accelerating structure.