GENERATION OF SHORT BUNCH ELECTRON BEAM FROM COMPACT ACCELERATOR FOR TERAHERTZ RADIATION*

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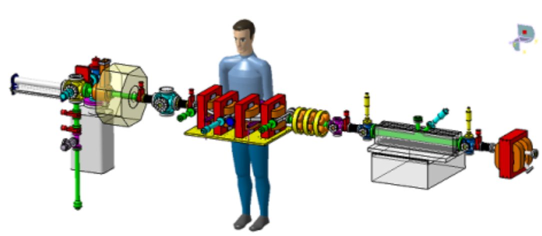
Abstract

We are developing a new compact accelerator system to generate a high power terahertz (THz) radiation at the Institute of Advanced Energy, Kyoto University. THz radiations are produced by injecting ultra-short and intense electron pulses to a short plannar undulator. The bunch compression characteristic by the newly installed chicane was investigated by observation of a coherent part of an optical transition radiation (OTR). As the result, the chicane can compress the electron bunch at the laser injection phase from 10 to 40 degree. The beam energy and relative rms energy spread were also measured and the results were 4.6 MeV and 1.3 %, respectively.

INTRODUCTION

A new compact high-power THz radiation source is under construction at the Institute of Advanced Energy, Kyoto University [1]. High-brightness electron beams are generated by a 1.6-cell S-band BNL-type photocathode RF-gun [2] installed with an emittance compensation solenoid magnet. The electron bunch is compressed longitudinally by a 4-dipole magnetic chicane bunch compressor. A triplet quadrupole magnets are installed downstream the chicane for the electron beam matching to the undulator. A Halbach type undulator is used as a radiator. The photocathode is illuminated by a picosecond UV lasers. The system is compact with the total length less than 5 m and located in the same accelerator room with Kyoto University Free-Electron Laser (KU-FEL) [3] to share the RF-power source and the picosecond UV laser. THz radiation will be generated from the undulator by coherent synchrotron radiations (CSR) in the 1st stage of the THz source development. The schematic view of the system is shown in Fig. 1.



Figures 1: Schematic view of the complete beam line of the compact THz-FEL amplifier system

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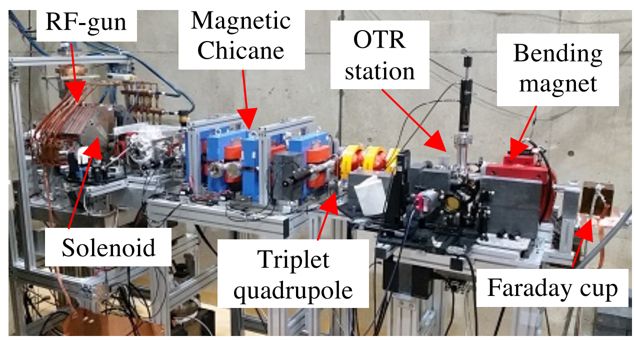
For the beamline construction, the photocathode RF gun and the laser system were completely installed and the first electron beam was generated in April 2015 and the beam properties have been measured [4]. The magnetic chicane bunch compressor and the triplet quadrupole were installed in March 2016. To investigate the bunch compression characteristics by the magnetic chicane, a coherent part of the optical transition radiation (OTR) [5] was measured to estimate the electron bunch length. The picture of the beamline with the current set up is shown in Fig.2. In this paper, we will report on the details of the experiments and results.



Figures 2: Beamline for the bunch compression characteristics investigation and the bunch length measurement.

EXPERIMENT AND RESULTS

Beam Energy and Energy Spread Measurement

Beam energy and energy spread were measured by using a bending magnet and a Faraday cup. The beam exits from the vacuum chamber through the titanium film (thickness 20 μm) extracting window at the deflection angle of 45 degree. The out-of-vacuum carbon faraday cup which is placed downstream to the beam extracting window was employed for measuring bunch charges. A lead slit with the thickness of 7 mm and the 1.5-mm gap was put behind the extracting window. The slit gap centre was 175 mm in the horizontal and 165 mm from initial beam axis center in the vertical away from the bending magnet center.

The beam energy and energy spread measurements were performed at the RF power of 9 MW, the number of laser pulse in one macro-pulse was 4 pulses and the total pulse energy was 124 μJ, the laser injection phase of 30 degree which provides a high OTR intensity investigated by roughly laser injection phase scanning. This condition gave the total bunch charge of 250 pC (63pC per bunch).

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The triplet quadrupole was adjusted to focus the beam at the extracting window. The filtered bunch charge by the slits was measured by scan the bending magnet current. The beam energy was calculated by tracking simulation using General Particle Tracer (GPT) code [6]. The measured bunch charge as a function of the beam energy is shown in Fig.3.

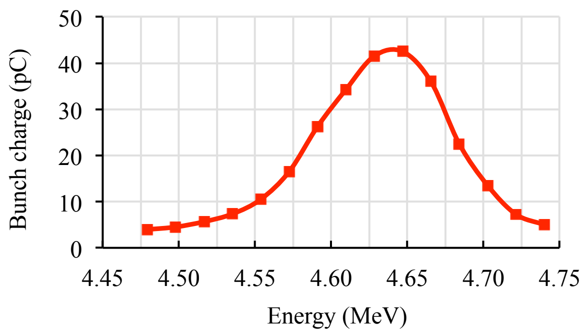

Figure 3: Bunch charge measurement result as a function of the beam energy.

By fitting a Gaussian distribution curve, the beam energy is deduced to be 4.63 MeV and the rms energy spread is 0.059 MeV which corresponds to the relative rms energy spread of 1.27 %. The calculated energy resolution of the system is 0.04 MeV or 0.86 %.

Bunch Compression Characteristic

The magnetic chicane bunch compressor, which consists of 4 rectangular dipoles whose pole length is 65 mm, the pole width of 100 mm and the pole gap of 30 mm and the distance between the magnets is 125 mm, was installed. The bunch compression characteristic was investigated by observing a coherent part of an OTR. At the wavelength longer than the bunch length, the OTR becomes a coherent radiation whose intensity is proportional to the square of the number of the electron per bunch. The power spectrum (P_{tot}) which is emitted by a bunch of N particle can be calculated by

$$P_{tot}(\lambda) = P(\lambda)[\, N + N(N\text{-}1)|f(\lambda)|^2] \,, \qquad (1)$$

where $P(\lambda)$ is the spectral radiation power from a single electron and $f(\lambda)$ is the bunch form factor defined by

$$f(\lambda) = |\, dz\, e^{i2\pi z/\lambda} s(z)\,|\,. \qquad (2)$$

For the OTR measurement, we used a thin aluminium foil as an OTR radiator arranged at the angle of 45 degree with respect to the beam direction. The OTR was extracted from the vacuum chamber through a Z-cut natural crystal quartz window and was focused by two off-axis parabolic mirrors. We used a pyroelectric detector (PHLUXi model PYD-1-018 with lens and visible light filter) for the OTR intensity measurement. The detector was attached to two-dimensional translation stage in order to find a focusing point by two-dimensional scanning. The measurement set up is shown in Fig. 4.

The measurement was performed at the RF power of 9 MW and the total laser pulse energy of 300 μJ with 4 pulses in a macro-pulse. The laser energy was increased from the electron beam energy measurement in order to obtain higher OTR intensity and higher signals from the detector. The OTR intensity was measured under the different laser injection phase conditions in both uncompression and compression conditions of the chicane. The chicane magnetic field was adjusted to 71 mT for the compression condition. The measurement results of the OTR intensity and the bunch charges are shown in Fig.5 (a) and (b), respectively.

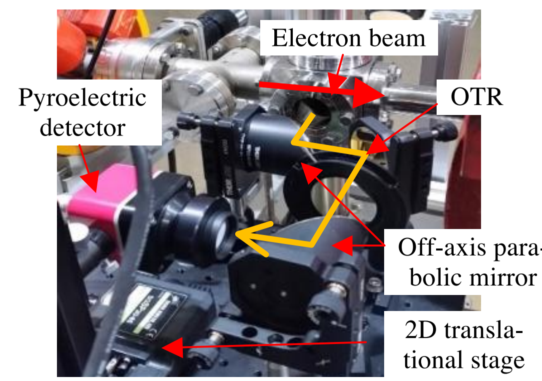

Figure 4: OTR intensity measurement set up

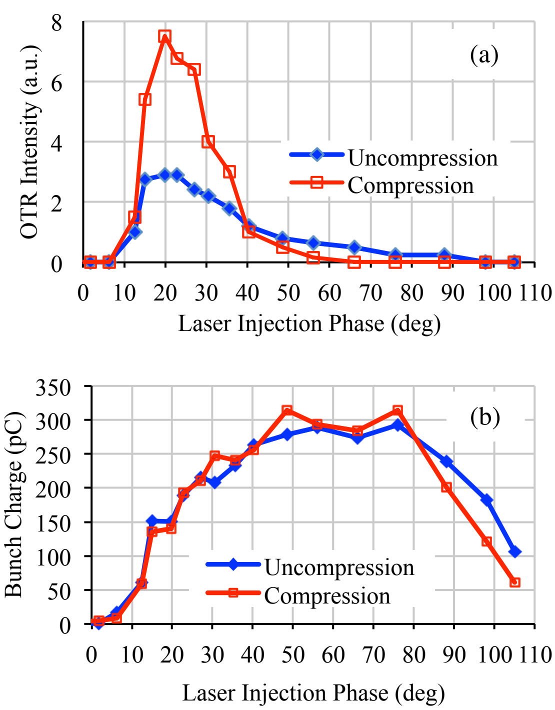

Figure 5: a) The OTR intensity b) bunch charge as a function of laser injection phases

Figure 5 (a) clearly shows that the OTR intensity can be enhanced by the chicane excitation at the laser injection phase from 10 to 40 degree while Fig.5 (b) shows that the bunch charges at the same laser injection phase were not changed by exciting the chicane magnets. It means that the chicane can shorten the bunch length leading to increase the bunch form factor, $f(\lambda)$ in equation 1. Conversely, at the laser injection phase more than 40 degree, the chicane lengthens the bunch length.

Bunch Length and OTR Spectrum Measurement

The particle distribution and frequency information of an electron bunch can be obtained by measuring OTR spectra measured by a Michelson interferometer. The OTR entering the interferometer was split into two beams by a sapphire beam splitter. The combined two beams enter a detector and detected signal intensity dependence on path difference called interferogram was recorded. In general, the interferogram has a symmetry shape. By assuming the longitudinal particle distribution to be Gaussian distribution, the electron bunch length can be roughly estimated by the center peak width divided by $\sqrt{2}$ [5]. The frequency component of the OTR also can be calculated from the interferogram by Fast Fourier Transformation.

The measurement was performed at the RF power of 9 MW, the laser energy of 300 μJ with 4 pulses and the laser injection phase of 20 degree where the maximum OTR intensity was obtained by the bunch compression experiment (Fig.5 (a)). This condition gave the beam energy of 4.6 MeV and the bunch charge of 138 pC. The chicane magnetic fields were 71 mT. The same pyroelectric detector as the OTR intensity measurement was used. The Michelson interferometer set up is shown in Fig. 6.

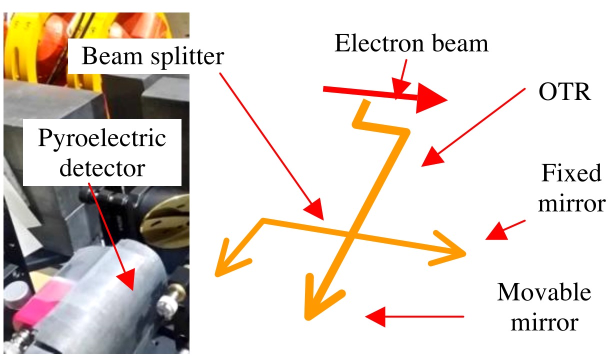

Figure 6: The Michelson interferometer set up.

Figure 7 (a) shows the interferogram measured by the Michelson interferometer. The red dash line is a Gaussian curve fitted to the central peak of the interferogram. In this case, the rms width of the curve is 0.41 mm and the calculated bunch length is 0.29 mm. The corresponding power spectral density calculated by the Fast Fourier Transform is shown in Fig.7 (b). Since the rms pulse length of electron beam generated from RF gun in the same condition is estimated by GPT simulation as 1 mm. It is clear that the chicane bunch compressor successfully compressed the electron bunch.

SUMMARY

We have measured the beam energy and energy spread from the compact accelerator for THz radiation. At the RF power of 9 MW and the laser injection phase of 30 deg, the measured beam energy is 4.63 MeV and the beam energy spread is 1.27 %. The bunch compression characteristic of the chicane has been investigated by using the optical transition radiation technique. The measured OTR intensity was enhanced at the laser injection phase range from 10 to 40 degree with the chicane current magnetic field of 71mT and the RF power of 9 MW. The compressed bunch length has been measured by Michelson interferometer and the measured rms bunch length was 0.29 mm at the laser injection phase of 20 deg. As the result, the chicane can successfully compress the electron bunch from the initial rms bunch length around 1 mm. Further measurements of the bunch length will be performed to investigate the optimum condition for the short bunch electron beam generation.

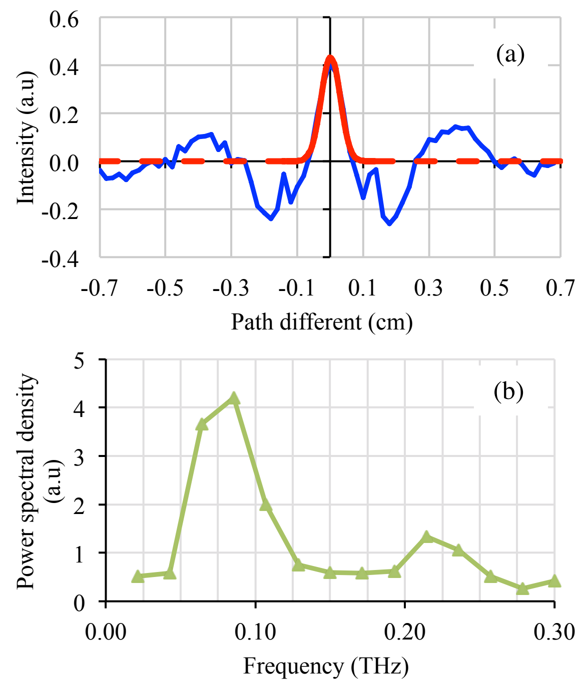

Figure 7: a) Interferogram of the OTR (solid line: actual measurement, dash line: Gaussian fit) and b) Corresponding OTR power spectral density

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