BEAM PARAMETER MEASUREMENTS OF FS-THZ LINAC AT PAL*

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Abstract

At Pohang Accelerator Laboratory, a femto-second (fs) THz facility was constructed for the experiments using femto-second THz radiation. The fs-THz radiation is generated from 60-MeV electron linac which consists of a photocathode RF gun, two accelerating columns, and two magnetic-chicane bunch compressors. The coherent transition radiation (CTR) is used for THz radiation generation. To generate high intensity THz radiation, the electron bunch length should be smaller than 200 fs. We report THz image obtained using IR-CCD camera and measured beam parameters including charge, emittance, and transverse beam size.

INTRODUCTION

Coherent radiation is produced when the radiation wavelength is equal to or longer than the electron bunch length. Therefore we can generate coherent THz radiation by using the femto-second electron bunches.

The total spectral radiation power from a mono-energetic bunch of N electrons is [1]

$$P(\omega) = p(\omega)N[1+(N-1)f(\omega)], \tag{1}$$

where $p(\omega)$ is the spectral radiation power from a single electron and $f(\omega)$ is the form factor which is the Fourier transform of the longitudinal bunch distribution. The form factor is $f(\omega)=\exp(-\omega^2\sigma^2/c^2)$ for a Gaussian distribution with the standard deviation σ. First term and second term in square brackets correspond to incoherent radiation and coherent radiation, respectively.

Transition radiation occurs when an electron passes through an interface between with different dielectric constants [2]. For a relativistic electron incident on a perfect conductor, the emitted radiation energy per solid angle and frequency range is [3]

$$\frac{d^2W}{d\omega d\Omega} = \frac{e^2\beta^2}{4\pi^2 c}\frac{\sin^2\theta}{(1-\beta\cos\theta)^2}, \tag{2}$$

where β is the relativistic velocity and θ is the emission angle with respect to the normal to the interface.

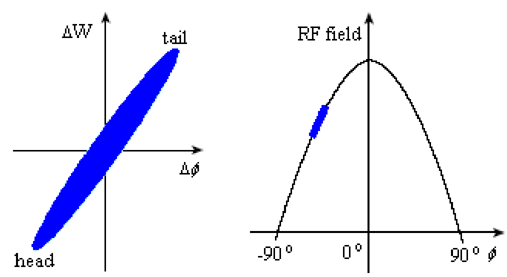
From Eq. (1) and (2), the energy of CTR generated from N electron is

$$\frac{d^2W_N}{d\omega} = N^2\frac{d^2W}{d\omega}f(\omega). \tag{3}$$

BUNCH COMRESSION

An electron bunch with 800-fs length and 0.5-nC charge generated from cathode by using laser is lengthened to about 1.5 pico-second (ps) due to the space charge effect. Therefore the bunch length has to decrease to about 100 fs for the generation of coherent fs-THz radiation, which is achieved by using the chicane bunch compressor.

For being compressed during passing the chicane magnets , an electron bunch has to be chirped that bunch head has lower energy than bunch tail as shown in Fig. 1(a). To chirping an electron bunch, it must be accelerated in accelerating column at forward of RF crest as shown in Fig. 1(b).



(a) (b)

Figure 1: Energy chirping in longitudinal phase space (a) and RF phase in accelerating column (b).

A chirped bunch is compressed passing the chicane magnets because the bunch head with lower energy passes through the longer path than the bunch tail with higher energy as shown in Fig 2. The relation of the relative position, l_i, compared to a reference particle, of an arbitrary electron before chicane and the relative position, l_f, after chicane is

$$l_f = l_i + R_{56}\delta + T_{566}\delta^2, \tag{4}$$

where R_{56}, T_{566} are the first and second momentum compaction factor, respectively, and $\delta(=\Delta p/p)$ is momentum spread. If R_{56} is determined to satisfy Eq. (5),

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$$l_i + R_{56}\delta = 0\,, \tag{5}$$

we can calculate the length of the compressed electron bunch. Because T_{566} of chicane bunch compressor is

$$T_{566} = -\frac{3}{2}R_{56}\,, \tag{6}$$

the compressed bunch length becomes

$$l_f = \frac{3}{2}\delta l_i\,, \tag{7}$$

and the longitudinal bunch distribution in phase space makes a bend due to Eq. (7) (see Fig. 3(b)). For this case, RF curvature gives small effect.

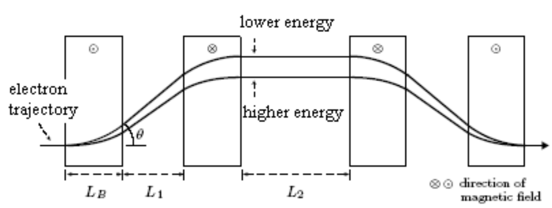
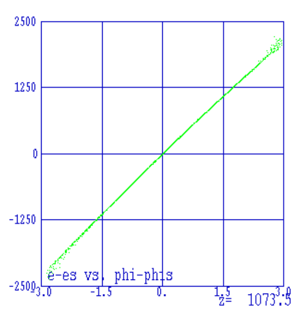
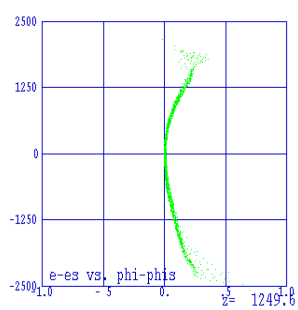


Figure 2: Chicane (rectangles) and electron beam trajectory.

Fig. 3 shows the bunch distribution in phase space before and after chicane which is results of PARMELA code simulation. The rms bunch length is 1.5 ps before the chicane and 80 fs after the chicane. The electron beam energy and charge at the chicane are 55 MeV and 0.5 nC, respectively, and R_{56} is -2.11 cm. Because the bunch length is below 100 fs, THz radiation with desired intensity can be obtained by using CTR.

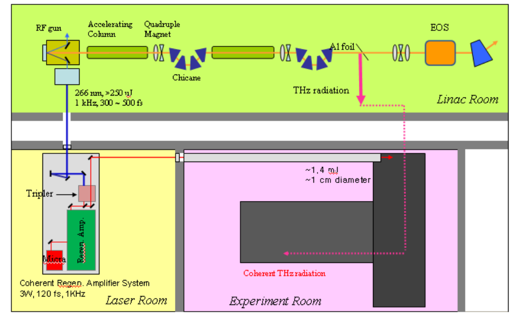


(a)

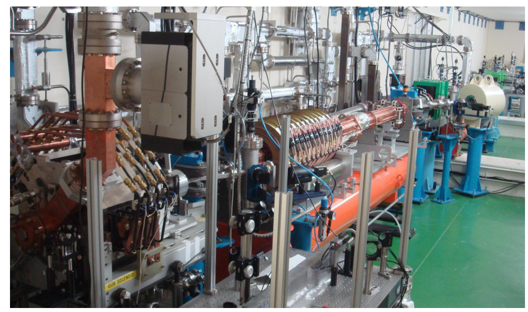


(b)

Figure 3: PARMELA simulation result for bunch distribution in phase space before (a) and after (b) chicane. The horizontal axis is distance between a synchronous particle and arbitrary particles in degrees (1 degree is about 1 ps) and the vertical axis is energy difference between a synchronous particle and arbitrary particles in KeV.



(a)



(b)

Figure 4: Layout of PAL fs-THz facility (a) and view of linac tunnel (b).

BEAM EMITTANCE MEASUREMENT

Figure 4 shows layout of PAL fs-THz facility and the picture of linac tunnel.

The energies of electron beam at RF gun, first accelerating column and second accelerating column are 5 MeV, 40 MeV and 75 MeV, respectively, and the energy of chirped electron beam is 60 MeV.

The transverse beam emittance is measured by quadrupole scanning method using a previous quadrupole magnet of the second quadrupole doublet and YAG screen placed in front of the target where THz radiation is generated.

We measured the beam size, σ, as to the change of the quadrupole strength, k. Fitting $\sigma(k)$ with a parabola ($(\sigma(k))^2 = ak^2 + bk + c$) gives

$$\begin{aligned} a_1 &= \frac{a}{l^2 d^2}\,, \\ a_2 &= \frac{-b - 2lda_1}{2l^2 d}\,, \\ a_3 &= \frac{c - a_1 - 2la_2}{l^2}\,, \end{aligned} \tag{8}$$

where d is distance between the quadrupole magnet and the screen and l is the quadrupole length. Then emittance becomes

$$\varepsilon = \sqrt{a_1 a_3 - a_2^2}\,. \tag{9}$$

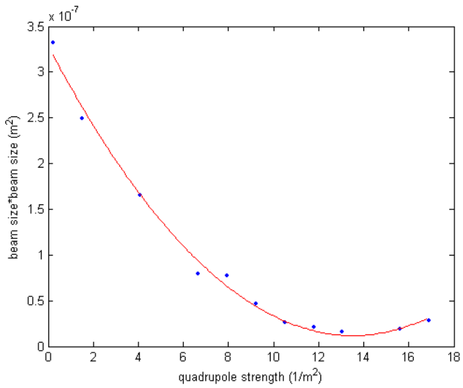
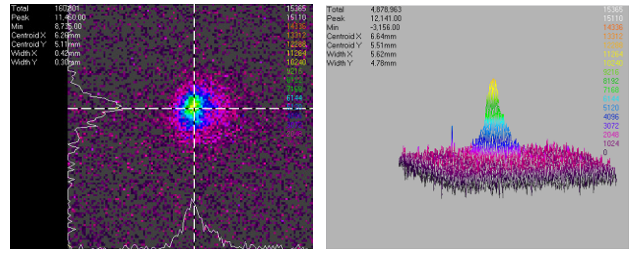


Figure 5: The result of quadrupole scanning method for emittance measurement.

Fig. 5 shows plot of the measured data and the fitting result. And the normalized rms emittance calculated by Eq. (6) is 1.5 mm·mrad.

THZ RADIATION IMAGING

0.5-mm thickness Al foil is fabricated as THz radiation target. Fig. 6 shows THz radiation image taken by using IR-CCD camera (Spiricon Pyrocam III) placed 50-cm distance from THz radiation target. At same location, THz radiation energy measured by using Golay cell detector is 1 μJ. This energy value is going up to the goal energy of PAL fs-THz facility, 10 μJ, by installing the transmission pipe filled with dry air to reduce water absorption of THz radiation [4] and linac commissioning.



(a) (b)

Figure 6: 2D (a) and 3D (b) image of THz using IR-CCD camera. CCD size is 12.4 mm × 12.4 mm.

FUTURE WORKS

For electron bunch length and jitter measurements using electro-optic (EO) crystal method and streak camera, etc., EO setup and optical transition radiation (OTR) setup are being installed.

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