ZZELECTRON- LINAC BASED FEMTOSECOND THZZZZZ ZRADIATION SOURCE AT PAL*

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Abstract

A 60-MeV electron linac for intense femto-second THz radiation source is under construction at PAL, which is the beamline construction project to be completed by 2008. To get intense femto-second THz radiation up to 3 THz, the electron beam should be compressed down to below 100 fs. The linac will use an S-band photocathode RF-gun as an electron beam source, two S-band accelerating structures to accelerate the beam to 60 MeV, a chicane-type bunch compressor to get femto-second electron bunch, and an optical transition radiation (OTR) target as a radiator. The PARMELA code simulation result shows that the 0.2 nC beam can be compressed down to a few tens of femto-seconds, and the higher charge of 0.5nC to about one hundred femto-seconds. Also, the linac will be able to provide femto-second electron beam for electron pulse radiolysis and compton-scattering experiment for femto-second X-ray.

INTRODUCTION

THz radiation source which can provide rich science and unexplored technology is becoming popular. And, sub pico-second radiation at that wavelength can provide an unprecedented probe for ultra fast dynamics like electronic excitations and magnetic excitations [1]. Pohang Accelerator Laboratory (PAL) is constructing a 60-MeV electron linac for intense femto-second THz radiation source, which is the beamline construction project to be completed by 2008. The radiation wavenumber to provide is 10-100 cm^{-1} (0.3 - 3 THz) and the radiation pulse duration should be shorter than 200 fs.

DESIGN

To achieve this goal, we will make use of relativistic electron beam with the bunch length of shorter than a few hundred femto-seconds. Relativistic particles emit incoherent radiation at all wavelengths, and additional enhanced coherent radiation at wavelengths of the order of the bunch length and longer. The total radiated spectral power from a mono-energetic bunch of N_e electrons at wavelength λ is

$$P(\lambda) = p(\lambda)N_e[1 + (N_e - 1)f(\lambda)], \quad (1)$$

where $p(\lambda)$ is the spectral radiation power from a single electron and $f(\lambda)$ is a form factor for an azimuthal symmetric bunch, which is the Fourier transform of the actual particle distribution. The first term in the square brackets is the incoherent part of the radiation while the second term corresponds to the coherent radiation which is N_e times the incoherent part assuming $f(\lambda) \approx 1$. The form factor is defined as

$$f(\lambda) = |\int S(x)exp\{i(2\pi x/\lambda)\}dx|^2. \quad (2)$$

where $S(x)$ is the normalized longitudinal density distribution of electrons in a bunch.

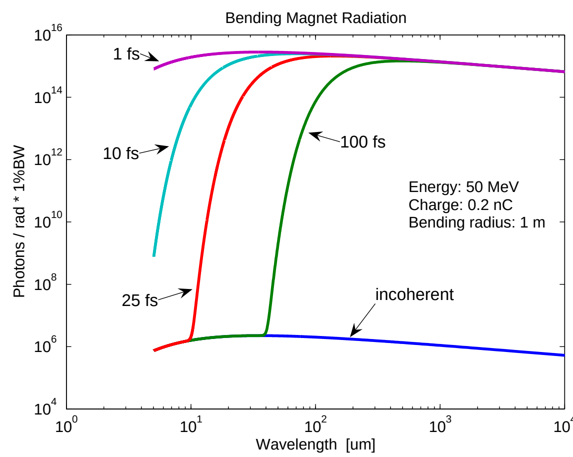

Figure 1: Coherent enhancement of synchrotron radiation from a bending magnet at different bunch lengths in rms.

Figure 1 shows the coherent enhancement of synchrotron radiation from a bending magnet at different bunch lengths in rms. The parameters used for the calculation are an electron beam energy of 50 MeV, a bending radius for synchrotron radiation of 1 m, and the electron bunch charge of 0.2 nC. The photon flux of coherent radiation is much higher than that of the incoherent part, simply N_e times.

From Figure 1, one can find how small the bunch length should be to get coherent THz radiation. Coherent enhancement of radiation is determined by the bunch form factor in Eq. (2). The required bunch length is as short as one tenth of the period of radiation to get the bunch form factor close to 1. For example, to get 10 THz radiation (period = 100 fs), the bunch length should be smaller than 10 fs, which is obviously impossible to get with 0.2 nC charge beam. So, the target bunch length to achieve in this project is about 50 fs with 0.2 nC beam, which can generate coherent THz radiation below 3 THz.

Figure 2 depicts the layout of the electron linac. The linac will use an S-band photocathode RF-gun as an elec-

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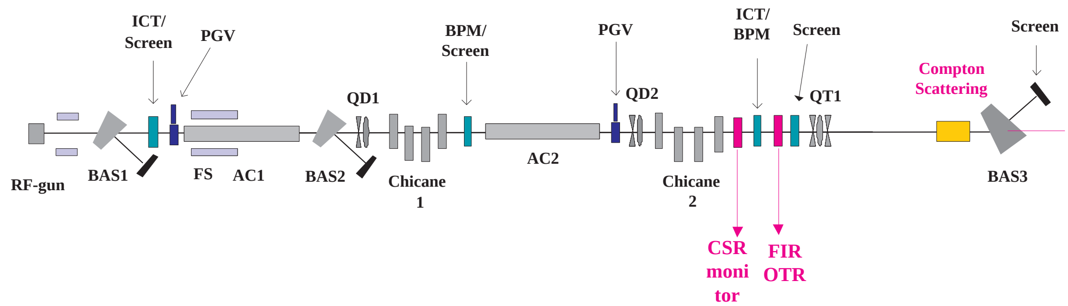


Figure 2: Layout of FIR Linac. (QD: quadrupole doublet, ICT: integrated current transformer, FS: focusing solenoid, AC: accelerating column, QT: quadrupole triplet, OTR: optical transition radiation, BAS: beam energy analyzer, and YAG: YAG screen).

Table 1: Parameters of the Linac

Parameters	Value
Beam energy	60 MeV
Beam Charge	0.2 - 0.5 nC
Beam Emittance	5 mm-mrad
Beam Pulse Repetition rate	60 Hz max.

Table 2: Relation of bunch charge and bunch length

Beam charge	Bunch length after RF-Gun	Bunch length after chicane
0.2 nC	0.5 ps	50 fs
0.5 nC	2 ps	150 fs

tron beam source, two S-band accelerating structures (AC1 and AC2) to accelerate the beam to 60 MeV, a chicane-type bunch compressor to get femto-second electron bunch, and an optical transition radiation (OTR) target as a radiator.

Parameters of the Linac are listed in Table 1. The beam energy is 60 MeV and the beam charge is 0.2 to 0.5 nC. The relation of bunch charge and bunch length is shown in Table 2. The bunch length is designed to be 50 fs with 0.2 nC beam and 150 fs with 0.5 nC. To get short bunch length after bunch compression, the bunch length at the gun is 0.5 ps with 0.2 nC beam, which is the reason why the emittance is relatively high, 5 mm-mrad.

As a wide-band radiation source, optical transition radiation was chosen rather than bending magnet radiation which is difficult to get a good pointing stability of radiation. On the other hand the undulator radiation which is narrow-band is not going to be used at the beginning, but the space is reserved, because the temporal length of the radiation exceeds 1 ps due to the wiggling motion of electron beam in undulator.

Optical transition radiation is generated when an electron crosses the boundary between two different media. Coherent transition radiation energy obtained from N_e electrons is [2]

Table 3: OTR energy vs. bunch charge

Bunch charge [nC]	Radiation energy [μJ]
0.2	3.5
0.5	22
1	88

$$\frac{dW_N}{d\omega} = {N_e}^2 \frac{dW_1}{d\omega} |f(\omega)|^2 \quad (3)$$

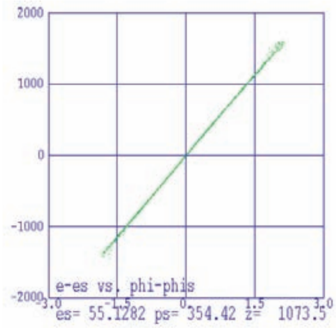
where $\frac{dW_1}{d\omega}$ is the radiation energy generated by single electron, and $f(\omega)$ is the form factor defined in Eq. (2). Table 3 shows the optical transition energy as a function of bunch charge assuming the bunch form factor of 1. A dramatic increase of radiation energy is expected with 1 nC while the radiation bandwidth must be limited because a few tens of femto-second bunch is impossible to get with 1 nC, even with 0.5 nC. So, there should be a compromise between the achievable radiation bandwidth and the radiation energy.

SIMULATION RESULT

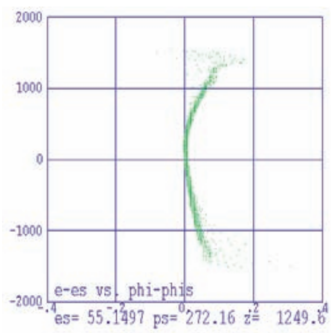
The beam dynamics design was carried out by using the PARMELA code. It was designed to be that the beam with 0.2 nC charge can be compressed down to about 30 fs in rms at the position of OTR target by Chicane-2. Figure 3 shows the bunch profile before and after Chicane-2. The rms bunch length is 920 fs before the chicane and 29 fs after the chicane. The parameters of Chicane-2 used in the simulation are: the beam energy is 55 MeV, the bending angle is 10 degrees, and R_{56} is -2.07 cm.

Beam dynamics design was also done for higher charge of 0.5nC. As a result, the bunch length is expected to be about one hundred femto-seconds.

Figure 4 shows the longitudinal bunch profile of electron beam after the 0.2 nC beam is compressed in Chicane-2, which is calculated by using the PARMELA code data. Making use of the longitudinal bunch profile, we can calculate the bunch form factor of the given distribution. Figure 5 depicts the bunch form factor at different bunch charges,



(a)



(b)

Figure 3: PARMELA simulation result: bunch shape before (a) and after (b) Chicane-2. *es* represents the synchronous particle energy, *phis* the synchronous particle phase. The vertical axis is *e - es* in MeV and the horizontal axis is *phi - phis* in degrees. One degree corresponds to about 1 ps.

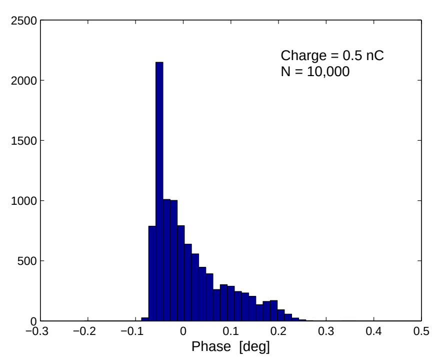


Figure 4: Longitudinal bunch profile of electron beam after the 0.5 nC beam is compressed in Chicane 2

0.2 nC and 0.5 nC, as a function of radiation wavelength. The bunch form factor at 100 μm reaches 0.7 with 0.2 nC beam while it is at most 0.2 with 0.5 nC beam.

In the PARMELA code simulation, the effect of CSR (Coherent Synchrotron Radiation) in the chicane was not included. CSR in the chicane deteriorates the electron beam energy distribution, which causes an increase of emittance and bunch length. The effect of CSR will be checked with other simulation code like ELEGANT.

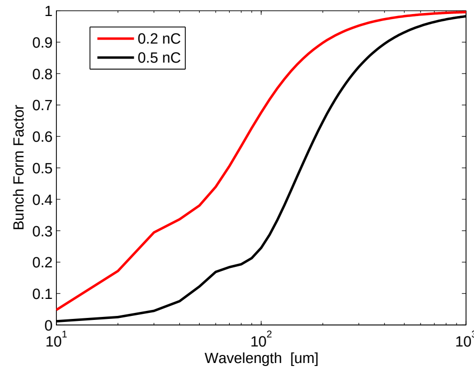


Figure 5: Bunch form factor at different bunch charges, 0.2 nC and 0.5 nC.

Figure 6: Photo of the linac tunnel.

CONSTRUCTION STATUS AND SUMMARY

The construction of the linac is on the way as shown in Fig. 6. The installation will be completed at the end of 2007 and the beam acceleration test will start at the beginning of 2008.

The 60-MeV electron linac was designed to generate intense femto-second THz radiation with the radiation wavenumber of 10-100 cm^{-1} (0.3 - 3 THz) and the radiation pulse duration of shorter than 200 fs. The linac will be able to be used for other applications such as electron pulse radiolysis, X-ray generation by Compton scattering, and SASE-FEL experiments, etc. A space after the chicane 2 is reserved for Compton-Back-Scattering experiment and FEL experiments as shown in Fig. 2.

REFERENCES

[1] DOE-NSF-NIH Workshop on Opportunities in THz Science, February 12-14, (2004).

[2] L. Wartski, et al., Journal of Applied Physics, **46**, 8, 3644 (1975).