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TERAHERTZ FEL SIMULATION IN PAL XFEL

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Abstract

Terahertz radiation is being used in various fields such as imaging, diagnosis, inspection, etc. For the Terahertz research, the Pohang accelerator laboratory (PAL) is planning to make a terahertz free electron laser based on self-amplified spontaneous emission (SASE). Using free electron laser method, we will be able to conduct the THz-pump x-ray probe experiment. For the terahertz free electron laser, we conducted the simulation study on the accelerator with e-beam energy below 40 MeV, using a photo-cathode RF gun, one s-band accelerator and one undulator shorter than 4 meters.

INTRODUCTION

In Pohang accelerator laboratory, we have a plan to make a THz FEL facility to conduct the THz pump X-ray probe experiment and other experiments of using THz radiation. For this purpose, a demanded condition of THz radiation is an intensity over 100 μJ, a various frequency range (5 to 20 THz) and a spectrum under 5%. To make a THz FEL facility which is satisfied with these conditions, we conduct the Accelerator simulation and FEL simulation using ASTRA and SIMPLEX [1, 2]. We conduct the ASTRA simulation for designing a photo-cathode RF gun, an S-band accelerator, accelerator solenoids, and two quadrupole magnet triplets. We conduct the SIMPLEX simulation using the result of ASTRA simulation. The simulation parameters are listed in Table 1 and 2, and the structure of the THz FEL accelerator is shown in Figure 1.

Table 1: Electron Beam Parameter

Electron beam	
Electron beam energy	25 MeV to 35 MeV
Electron beam charge	4 nC
RMS electron bunch length	1.8 mm
Peak current	265 A
Horizontal Emittance	4 mm-mrad
Vertical Emittance	5 mm-mrad
Energy spread	0.001

Table 2: Undulator Parameter

Undulator	
Type	Planar
Period	3.5 cm
K	1.6 to 3.321
Magnetic field	0.7 T to 1.016 T
Length	4 m
Gap	9 mm

ACCELERATOR SIMULATION

The wavelength of terahertz radiation is much longer than the wavelength of x-ray or UV radiation. Accordingly, the electron bunch length of the THz FEL is allowed to be as long as 1.8 mm. To make a THz FEL radiation, we need high peak current. To satisfy these conditions, we need a high electron charge over 4 nC.

The wavelength of the FEL radiation is calculated by the below equation.

$$\lambda = \frac{\lambda_u}{2\gamma^2}(1+\frac{K^2}{2})$$

λ is an FEL wavelength, λ_u is a period length of the undulator, K=93.4*$\lambda_u B_{peak}$. Using this equation, we can get the electron beam energy when the radiation frequency is in the THz range. When the undulator period length is 3.5 cm, the magnetic field of the undulator is under 1.016 T, undulator gap is 9 mm, and electron beam energy in 25 MeV to 35 MeV, the available range of the THz radiation wavelength is 5 THz to 30 THz. We make a specific electron beam condition using the ASTRA, which satisfies the electron beam parameter. The ASTRA simulation results are shown in Figure 2, 3, 4, and 5.

To generate a high charge electron beam, we should use a larger laser beam size in the input condition and control the gun solenoid condition. Using quadrupole triplets, we can match the electron beam between accelerator and undulator.

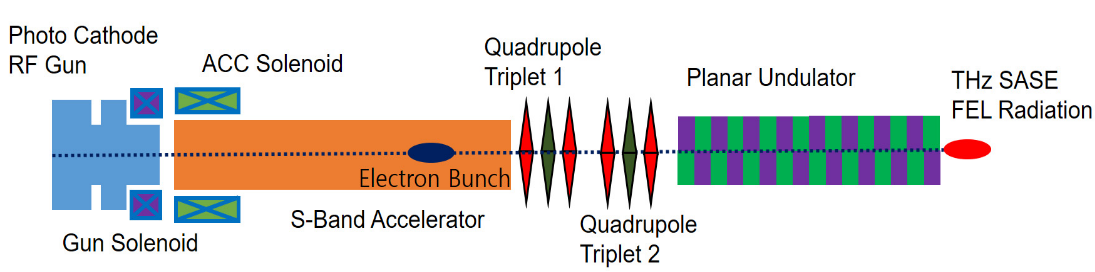

Figure 1: Schematic structure of THz FEL facility in PAL XFEL.

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When the electron beam energy is in a few tens of MeV range, the vertical focusing of the undulator is so high that the vertical electron beam size grows too much in the undulator. To overcome this, we need to make a very small vertical beam size at the undulator start position (z = 10.3 m) and we make a focal position of the horizontal beam at the middle of the undulator (z = 12.3 m).

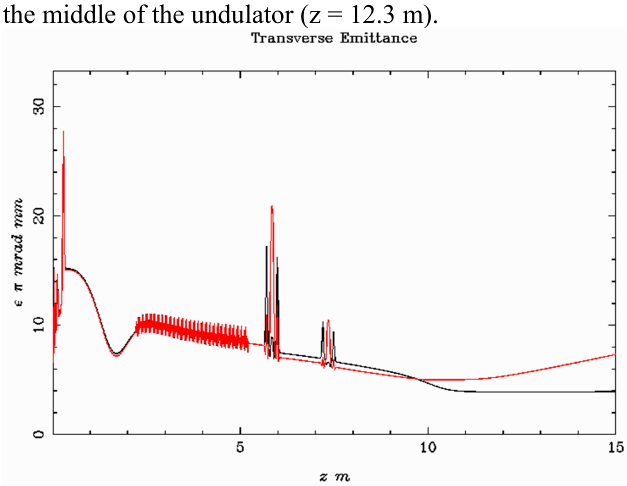

Figure 2: Transverse emittance of electron beam. Transverse emittance of the electron beam has controlled by the B field strength of the gun solenoid.

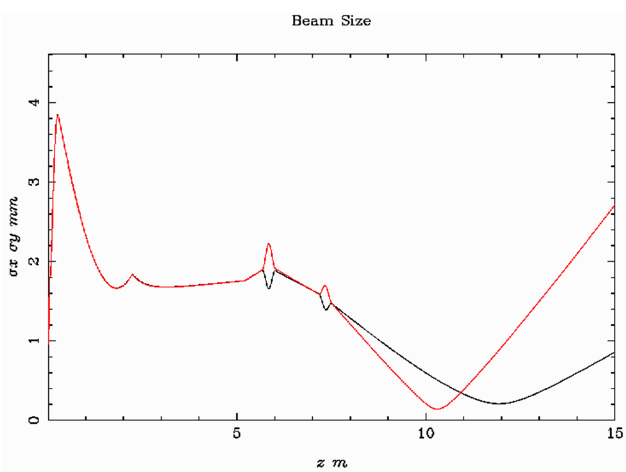

Figure 3: RMS electron beam size.

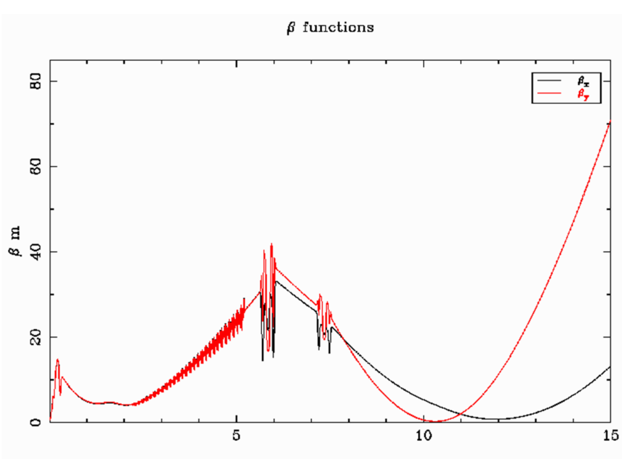

Figure 4: Beta function.

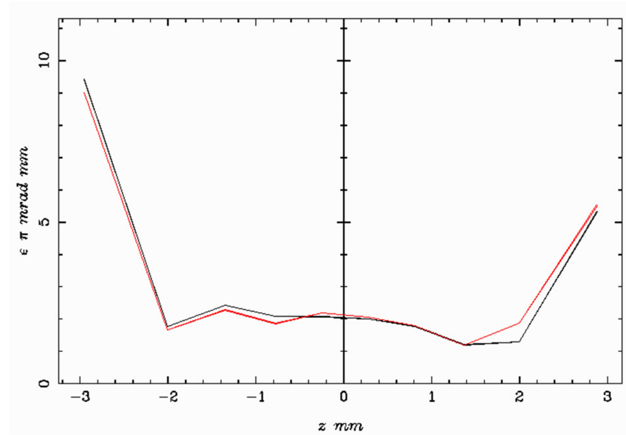

Figure 5: Slice emittance at the z =10.3 m.

The emittance is vertically 5 mm-mrad and horizontally 4 mm-mrad at the entering position of the undulator but the slice emittance of the electron bunch is much smaller than the result. The slice emittance of the electron beam centre is nearly 2 mm-mrad at the entering position of the undulator.

FEL SIMULATION

Using the result of the ASTRA simulation, we conduct the FEL simulation by using the SIMPLEX code [2]. We choose the same undulator installed in the PAL-XFEL soft x-ray line and reduce the undulator length to 4 m. Undulator parameters are shown in Table 2. After selecting the undulator parameter, we input the initial electron beam parameter at the undulator entrance. We use the result of the beta function and alpha function of ASTRA simulation at z = 10.3 m. The result of SIMPLEX simulation is shown in Figure 6,7,8, and 9.

Figure 6, 7, 8, and 9 show the FEL energy of each undulator and the electron beam condition. In our plan, we control the photon energy by changing the electron beam energy and undulator *K*. *K* is adjusted by the gap distance. The *K* value of 3.321 is the maximum *K* value of the undulator. The THz FEL range is 12.16 THz to 26.47 THz when the electron energy is 35 MeV and 6.17 THz to 17.77 THz when the electron energy is 25 MeV. The output FEL energies are over 300 μJ.

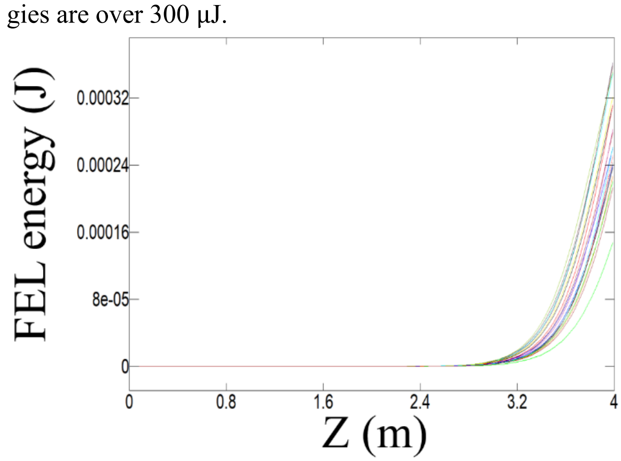

Figure 6: FEL energy of 35 MeV, K2.0, 26.47 THz.

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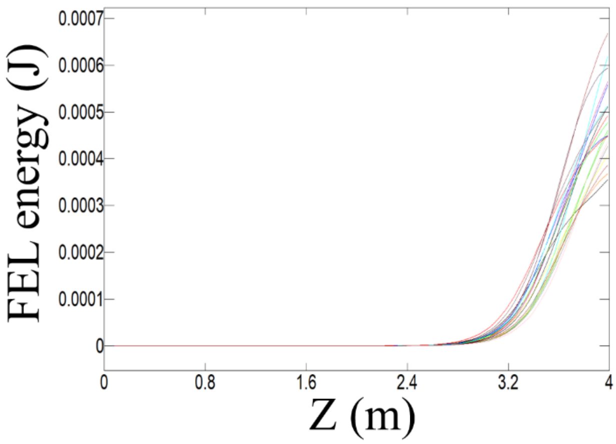

Figure 7: FEL energy of 25 MeV, K 1.6, 17.77 THz.

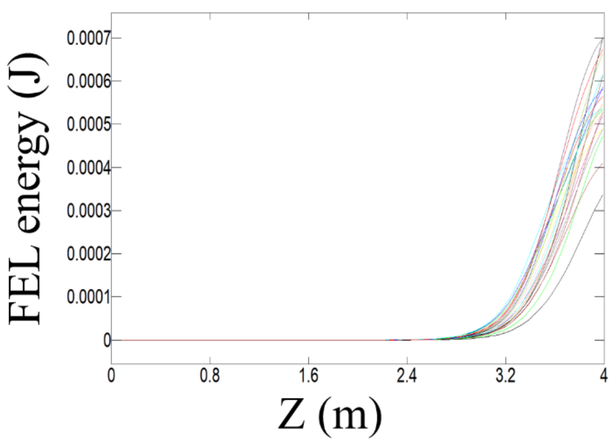

Figure 8: FEL energy of 35 MeV K 3.321, 12.16 THz.

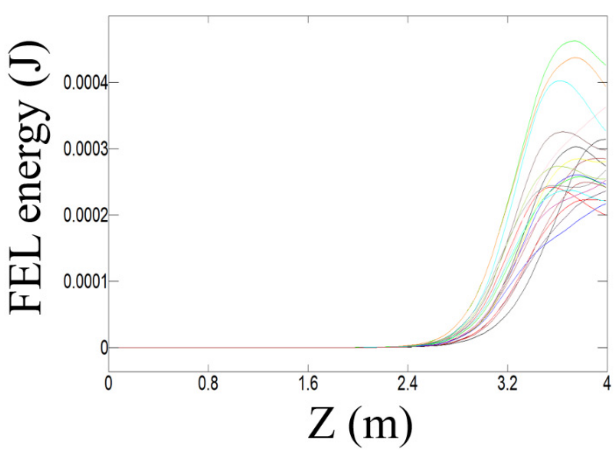

Figure 9: FEL energy of 25 MeV, K 3.321, 6.17 THz.

Figure 10 shows the spectrum of FEL. In Figure 10 (a), the 26.47 THz has the spectrum bandwidth of 2.2 % in FWHM, in (b) the 17.77 THz has the spectrum bandwidth of 2.7 % in FWHM, in (c) the 12.16 THz has the spectrum bandwidth of 3.0 % in FWHM, and in (d) the 6.17 THz has the spectrum bandwidth of 4.1 % in FWHM.

These results show the FEL photon energy can tune from 6.17 to 26.47 THz, the FEL intensity is over 300 µJ, and the spectrum bandwidth is under 5 %.

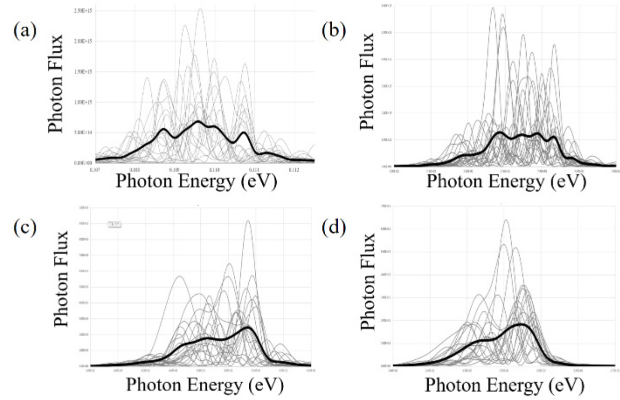

Figure 10: FEL spectrum of (a) 35 MeV, K 2.0, 26.47 THz, bandwidth 0.605 THz (b) 25 MeV, K 1.6, 17.77 THz, bandwidth 0.484 THz (c) 35 MeV K 3.321, 12.16 THz, bandwidth 0.362 THz (d) 25 MeV, K 3.321, 6.17 THz, bandwidth 0.254 THz.

CONCLUSION

In Pohang Accelerator Laboratory, we have a plan to construct a THz FEL facility. For this purpose, we conduct the FEL simulation and Accelerator simulation using ASTRA code and SIMPLEX code. Using this result, we determine the undulator length under 4 m. In the FEL simulation, the important parameter is the vertical focusing strength of the undulator. To overcome the vertical focusing strength, we make a very small vertical beam size using two quadrupole triplets. In this condition, the simulation's result shows the FEL energy over 300 µJ and spectrum bandwidth under 5 % with various THz FEL frequency. In the future, we will conduct the more specific simulation of matching of accelerator and undulator and search for the better THz FEL energy condition and a wide photon energy range.

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