BEAM LINE DESIGN AT THE CAEP THZ FREE ELECTRON LASER

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Abstract

China Academy of Engineering Physics (CAEP) is currently building a THz Free Electron Laser (FEL-THz) source which serves as a radiation light source used for research in a variety of experimental fields. In this paper, we present the design of the beam line, which was accomplished using PARMELA and TRANSPORT computer simulations. The accelerator consists of a 350 kV photocathode DC gun providing a pulsed electron beam, in conjunction with one cryomodule containing two 4-cell superconducting RF cavities. The energy of the electron beam is 7~8 MeV, and the maximum of the average beam current is 5 mA. A emittance typically below 10 pi mm.mrad can be achieved.

INTRODUCTION

Electromagnetic radiation in the frequency range from about 0.1 to 10 THz is known as the 'THz gap', which corresponds to wavelengths between 3mm and 30 μm, photon energies between 0.4 and 40 meV. It can be used in many regions, such as in pharmacy [1], in medicine and biology [2] and in security [3]. But there is lack of efficient sources and of sensitive detectors. Free electron laser can provide high power radiation and is monochromatic and tunable. Due to its excellent properties above, FEL-THz source is one of most perfect choices to generate THz radiation.

China Academy of Engineering Physics (CAEP) is currently building a THz Free Electron Laser source which serves as a radiation light source used for research in a variety of experimental fields. The performance of a free electron laser depends crucially on the electron beam parameters. Requirements at the undulator for our high power cw FEL are as follow: The electronic energy is 6-8 MeV, transverse emittance is less 10π mm·mrad, energy spread less 0.75%, beam length less 10 ps and the facility will radiate with a average power about 10 watt between the wavelength range of 100-300 m. A block diagram of the facility is shown in Figure 1. Its injector consists of a high DC voltage GaAs photocathode Gun drived by a frequency-doubled, mode-locked Nd:YLF laser, two solenoidal lens, a room temperature 1.3 GHz buncher cavity, a cryounit with two 4-cell superconducting cavities. And its transport line is antisymmetric to cancel chromatic aberration with four quadrupoles lens and two bend magnets. Undulator with resonance cavity is used to radiate THz laser from electron beam.

Not only analytical calculations are needed to give an estimate of the expected performance, but also numerical start-to-end simulations are required to account for various aspects of beam dynamics and to match the demands of wiggle [4]. In this paper, we present the optimize simulation results and give some parameters analysis. To account for space charge effects, beam dynamics code PARMELA [5] was used to simulate the module from cathode to wiggle without including electron-photon interaction. Dispersion section was simulated first by TRANSPORT [6], then by PARMELA.

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INJECTOR PROPERTIES

Design study of CAEP FEL-THz injector has been carried out by PARMELA supplemented by POISSON. Initial electron bunch produced at cathode by laser. Electron bunch is uniformly distributed with 6 mm in diameter transversely. Longitudinally, the bunch is 50 ps long with a Gaussian distribution whose FWHM value is taken to be 18 ps due to the rather long response time of GaAs. The gun operates at a nominal accelerating voltage of 320 kV and bunch charge of 90 pC. The average beam current is 5 mA with laser laser frequency 54.167 MHz. The total beam line of injector is 396.28 cm long, and the design machine parameters of injector are listed in Table 1.

The accelerating field gradient in the DC gun is not high, limited by the field emission and the punch through the ceramic insulator. The maximum field gradient is 4.12 MV/m on the cathode surface. The length of gun is 14.7 cm, and there is a nose at 9.8 cm to focus the beam slightly.

Table 1: 90 pC Elements Parameters

Element	Setting
DC gun	320 kV
1st Solenoid	303.2 Gs
Buncher	0.8 MV/m at zero crossing
2st Solenoid	214.6 Gs
SRF1 Cavity	12 MV/m
SRF2 Cavity	12 MV/m

Solenoidal lens S1 is right against the gun's anode plate and the fields overlap. It is 14 cm long. It could be used for transverse focusing and transverse emittance compensation. This work has been described elsewhere [7]. It is clear that solenoid works like thin lens, so that bunch radius does not change much before the lens with different solenoid current. It is better to set the magnetic field smaller in order to reduce space charge effect. On

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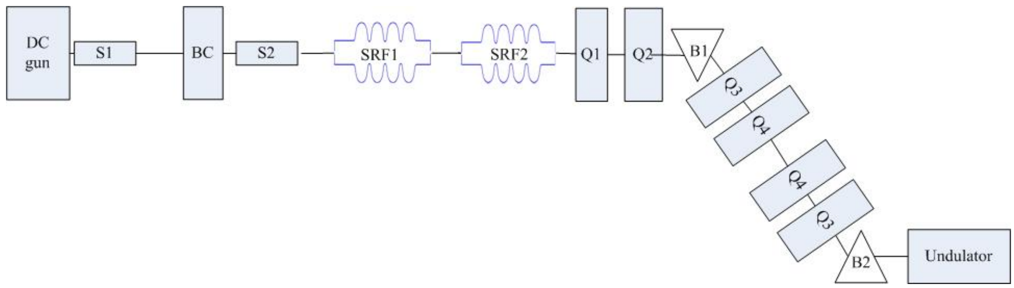

Figure 1: Block diagram of the CAEP FEL-THz facility. S1 and S2 are solenoidal lenses. BC is the RF Buncher Cavity. SRF1 and SRF2 the superconducting RF Cavities, Q1, Q2, Q3 and Q4 are quadrupoles, B1 and B2 are dipoles.

the other hand, a too small current would cause electrons hit the pipe.

Buncher is just a 1.3 GHz copper cavity, and will be utilised to decrease the bunch length. Here we use the zero-crossing phase. At this phase, beam has maximum energy spread, the direction of which is to the bunch centre, therefore it has maximum bunch compression. Its gradient is set to minimize the bunch length at the entrance of the first cell of SRF1. In order to reduce the required RF power, maximum field gradient along the z axis must be as small as we can. Also the small field gradient could result a large distance between buncher and SRF cavity. Here we set the maximum field gradient to 0.8 MV/m. The required cw RF power is then about 1 kW.

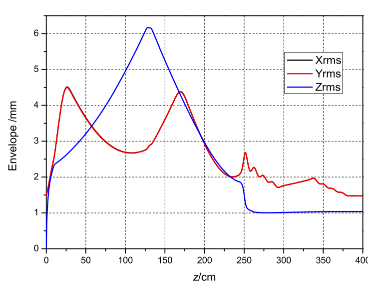

Figure 2: Optimized results of beam size and length.

The second solenoid is similar to the first solenoid, and is used to match the beam transversely into the cryouint. Ideally, the solenoid S2 strength is adjusted to position the beam waist at the entrance of the first cell of the SRF1 cavity, where also has the minimum bunch length.

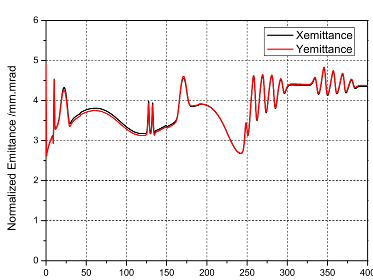

Figure 3: Optimized results of beam transverse emittance.

Superconducting cavity has a length of 70.64 cm. In order to accelerate beam energy to 7-8 MeV, we set the SRF cavity field gradient both to 12 MV/m on crest. The optimization method is as follow: Firstly, find a crest phase $\Phi 1$ of the 1^{st} cavity, then find crest phase $\Phi 2$ of the 2^{st} cavity at fixed $\Phi 1$, finally change crest phase $\Phi 1$ slightly with a fixed relative phase to get a compromised result.

Figure 4: Evolution of bunch rms energy spread.

The optimized simulation results of injector design can be found in Fig2-4. Figure 2 is the evolution of rms beam size and bunch length. From this figure, we can see that Xrms is 1.472 mm at the exit of injector, Yrms is 1.473 mm, rms bunch length 1.036 mm. Figure 3 is the rms transverse normalized emittance, 4.349 and 4.374 mm.mrad at X, Y direction respectively. The energy spread is shown in Figure 4, 0.785 keV, 0.105‰ in the end.

BEAM TRANSPORT SYSTEM

Electrons from injector with energy 7.5 MeV transport to wiggle by a achromatic section, which consists of two 45 degree bend dipole and four quadrupoles. The leading and trailing edge angles on the bending magnet B1 are 0 and 45 degree, respectively. According to the transport matrix theory, the chromatic aberration curve is antisymmetric for our antisymmetric achromatic section. A transfer line employs two quandrupoles to match the beam into the achromatic section as shown in Figure 1. In our work, we optimized the achromatic section first with transport matrix code TRANSPORT, and then tracked the beam with code PARMELA using the same parameters.

Because of the space charge effect, parameters of quadrupoles in PARMELA must have small changes. Table 2 shows the element parameters of achromatic section used in PARMELA.

Table 2: Parameters of Achromatic Section

Element	Setting
Quadrupole Q1	-86.6667 Gs/cm
Quadrupole Q2	100.0 Gs/cm
Dipole B1	1.33160 kG
Quadrupole Q3	-88.0952 Gs/cm
Quadrupole Q4	205.238 Gs/cm
Dipole B2	1.33160 kG

The optimized results show in Figure 5 and Figure 6. Figure 5 is the evolution of beam size and bunch length in achromatic section and wiggle without electron-photon interaction. The maximum RMS envelopes of x and y directions are less than 3 mm, and the bunch length is almost the same after the achromatic section. At the centre of wiggler, there is a waist in horizontal plane, which is required by electron-photon interaction. The vertical beam envelope is oscillated in wiggle because of the vertical focusing. Evolution of Beam RMS transverse normalized emittance in achromatic section is shown in Figure 6. Horizontal emittance increases first and then decreases. But the vertical emittance is almost the same in achromatic section.

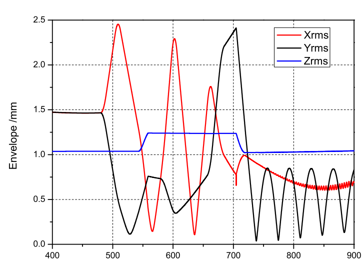

Figure 5: Evolution of beam size and bunch length in achromatic section and wiggle.

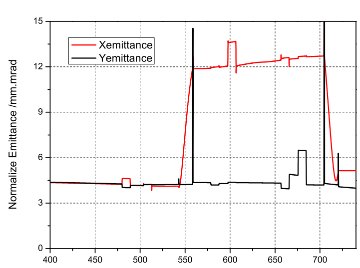

Figure 6: Evolution of Beam normalized RMS transverse emittance in achromatic section.

The optimized results of beam properties at the entrance of wiggle from PARMELA simulation are summarized in Table 3. From this table, it is shown that the beam properties are good enough to satisfy the requirement for CAEP FEL-THz facility.

Table 3: Beam Properties at the Entrance of Wiggle

Xrms(mm)	0.8831
Yrms(mm)	0.1379
Zrms(mm)	1.026
E(MeV)	7.4846
dE(%)	0.017
Xemit(mm.mrad)	5.016
Yemit(mm.mrad)	4.063

CONCLUSION

CAEP FEL-THz facility is under construction. Not only analytical calculations are needed, but also numerical simulations are required to account for various aspects of beam dynamics and to match the demands of wiggle. Transport matrix code TRANSPORT is used to match the achromatic section, and particle tracking code PARMELA used for particle transport with space charge effect. Elements parameters of system are optimized and the simulation results are good enough satisfy the requirement for CAEP FEL-THz facility. At the entrance of wiggle, the RMS horizontal normalized emittance is 5.016 πmm·mrad, the RMS bunch length is 1.026 mm, the beam energy is 7.4846 MeV and the RMS energy spread is 0.017% .

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