THE PKU TERAHERTZ FACILITY AT PEKING UNIVERSITY *

Kai Yu[#] , Shengwen Quan, Wencan Xu, Kui Zhao, Feng Zhu, Jiejia Zhuang
Institute of Heavy Ion Physics, Peking University, Beijing 100871, P.R.China

Abstract

The PKU Terahertz facility (PTF) is planned as a compact, high power Terahertz user facility found on the coherent undulator radiation concept and superconducting radiofrequency technology for the linear accelerator. Basing on a 3.5-cell DC-SC photoinjector, the PTF will provide high average power, coherent terahertz radiation with quasi-monochromaticity and wavelength tunable between 400um ~ 1200um, serving as a powerful tool for frontier researches and practical applications in the THz realm. Conceptual design of the PTF has been studied. Key components of the 3.5-cell DC-SC photoinjector have been prepared and the assembly of beamline is in progress.

INTRODUCTION

The terahertz (THz) region of electromagnetic spectrum which spans from 0.1 to 10THz (3 ~ 0.03mm) has a wide variety of potential applications, ranging from physics to biology, from material science to security technology. THz sources with different mechanisms have been reported in recent years, among which the bunched electron beam based THz sources has the distinguished feature of high power and spectral brightness. It has been demonstrated in many accelerator/storage ring facilities that relativistic speed electron beams, after compressed into picoseconds (or subps) can generate a huge amount of brilliant radiation in the THz range, several orders of magnitude higher than conventional THz sources[1]. For advanced THz applications, the main task is to decrease their size and cost.

An R&D program aimed at an inexpensive, compact THz facility is in Progress at Peking University. It is designed based on coherent undulator radiation concept and application of velocity bunching mechanism, utilizing the DC-SC photoinjector which has the characteristics of high stability and high average power. The PKU Terahertz Facility (PTF) will run in 400um ~ 1200um region.

SYSTEM DESCRIPTION

The schematic layout of the PTF is shown in Fig 1. It is composed of a 3.5-cell DC-SC photoinjector, a beam line with a solenoid and several diagnostic components, a planar permanent magnetic undulator and a bending magnet which delivers the used electrons to the dump. The whole system is less than 4 meters.

The 3.5-cell DC-SC photoinjector consists of a DC gun with voltage of 90kV and a 3.5-cell superconducting cavity located in a 2K crymodule operating at 1.3 GHz. It gets the beam to the energy of ~5MeV and creates an energy phase correlation suitable for bunch compression.

The solenoid C1 on the beam line performs emittance compensation for the beams. It regulates the transversal properties of the beams and matches them into the undulator.

A straight beam line guides the electron beam to the undulator. The drift section provides the necessary distance for bunch compression of velocity modulated beams. The undulator adopts a planar permanent magnet arrangement. The THz radiation is generated as coherent undulator radiation emitted by electron beams passing through it.

Quadrupoles Q1, Q2, slit K, bending magnet B1 and diagnostic screen S3 are used for energy spectrum and energy spread measurement. Emittance measurement is done with quadrupole Q2 and diagnostic screen S2. The two ICTs T1 and T2 at the exit of the injector and undulator respectively are employed to measure the beam current.

The design electron beam parameters for THz radiation are specified in Table 1.

Table 1: Design electron beam parameters for PTF

Beam energy	5.38 MeV
Bunch charge	20 pC
Bunch length (FWHM)	1 ps
Energy spread (rms)	0.5%
Emittance (rms)	2.6 mm mrad
Energy spread	0.5%
Micro-pulse rep. rate	81.25 MHz
Macro-pulse rep. rate	10 Hz
Duty cycle	5%

DC-SC PHOTOINJECTOR

The DC-SC photoinjector which provides high quality electron beams with low transverse emittance and high average current is the core component of the facility. By integrating a DC pierce gun with the superconducting cavity, the compatibility problem between superconducting cavities and the photocathode is avoided.

The DC gun provides 8ps (FWHM) long, high charge electron bunches at the cathode when the Cs_2Te photocathode is illuminated by a 266nm wave length laser. The cathode in the DC gun works at LN_2 temperature and exchangeable, separated from the superconducting cavity by a vacuum gap of 3.1 cm. As specially designed with consideration of the space charge effect, the DC gun

*Work supported by National Basic Research Project (No.2002CB713602)
[#]yukai@pku.edu.cn

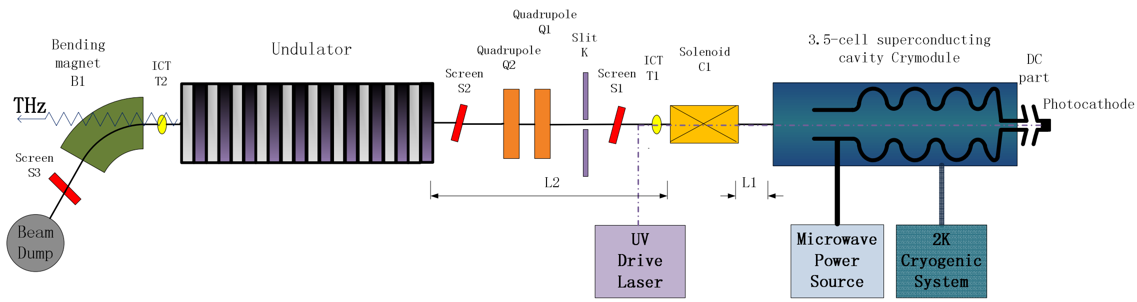

Figure 1: Schematic layout of the PKU Terahertz Facility.

can transversely focus the electron beams while pushing them into the following superconducting cavities. Thus the initial transverse emittance of the electron beam at the entrance of the 3.5-cell superconducting cavity is controlled ≤1.2 mm mrad.

The 3.5-cell superconducting cavity is a modified TESLA type cavity. The cells are made of 2.8 mm thick large grain niobium sheet with RRR > 400. They are fabricated by spinning, trimming and electron beam wielding, and post-treated by mechanical polishing, high pressure pure water rinsing and buffered electro-polishing (BEP). The whole procedure of preparation of the 3.5-cell superconducting cavity has been done at Peking University. Fig 2 shows the large grain niobium sheet and the 3.5-cell superconducting cavity

a)

b)

Figure 2: a) large grain niobium sheet and half-cell cavity b) 3.5-cell superconducting cavity with end-cavity components.

To obtain best performance and stability for high average current operation, several structure features of the cavity is specially designed. The two HOM couplers at the same end of the cavity are optimized for most efficient removal of high order mode power. Detailed beam dynamic calculation results of this injector were published in [2]. For electron beam with bunch charge of 20pC accelerated to 5.5 MeV, a transverse emittance of 2 mm mrad can be obtained.

BUNCH COMPRESSION

The optical performance of coherent undulator radiation depends critically on the parameters of the electron beam. To get high power, coherent THz radiation, it is important to get electron beams with short bunch length, which is comparative to the radiation wave length. We employed velocity bunching mechanism to complete bunch compression in the design of PTF. Specific energy-position correlation is created in electron bunch by accelerated "out of crest" in the injector. Then after slipping in the injector and drifting a certain section of distance, electron bunch will be automatically compressed into short bunch.

We studied the beam dynamics inside DC gun and accelerating cavity by simulation with PAMELA [2] Using the beam obtained from PAMELA at the exit of 3.5-cell cavity to match with OPTIM through the transport line. With OPTIM we could find the right solenoid magnetic strength as well as length of drift section, and used these values to track electron beam from the initial to the undulator. Our purpose is to choose the optimal RF phase at the entrance of accelerating cavity, the proper accelerating gradient and solenoid magnetic gradient to minimize the drift section for getting desired beam quality.

Our present scheme provides that the Acc. Gradient of 3.5-cell cavity is 15 MV/m and RF phase at entrance of the cavity is -66 degree. Solenoid on the beam line is 20cm long with magnetic field of 685 Gauss. Then Drift sections L1, L2 need to be 10cm, 70cm respectively. A compression factor of 9 was obtained from the simulation. It produces beam with bunch length less than 1ps and peak current of 20A at the undulator. The beam parameters before and after the compression are listed in

Table 2. and the PARMELA simulation results are shown in Fig 3.

Unlike chicane compression system, this design needs no magnets and bending angles on the transport line, which greatly lowers the total cost and size of the facility, as well as avoids the beam quality degradation due to the CSR

Table 2: Beam parameters before/after compression

Beam parameters	Acc. cavity entrance	Acc. cavity exit	Undulator entrance	Units
Bunch length (FWHM)	9.35	1.29	0.99	ps
Emittance	1.23	2.15	2.59	mm mrad
Beam radius	0.99	2.30	3.78	mm

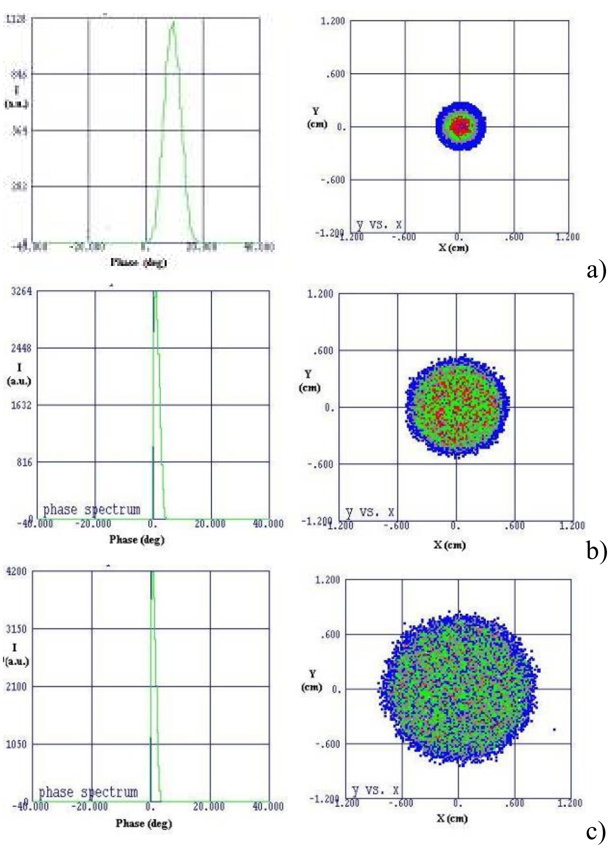

Figure 3: PAMELA simulation results of electron bunch a) at entrance of Acc. cavity, b) at exit of Acc. cavity, c) at entrance of undulator. Left and right frames, respectively: longitudinal profile and transverse profile.

THz PRODUCTION

The resonance condition of a laser pulse co-propagating with an electron bunch in an undulator is

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

where λ is the laser wavelength, λ_u is the undulator periodic length, γ is the Lorenz factor of the electrons and K is the undulator field parameter defined by $K=0.934B[T]\lambda_u[cm]$ with B as the peak magnetic field of the undulator. A planar permanent magnet undulator is considered in our project. It is a 20-period undulator with period length of 5cm. The choice of period number is determined by the bandwidth requirement. The peak magnetic field is adjustable from 0.39T to 0.70T. Tuning of the THz wavelength is always important to facility users. Varying the undulator gap to meet the resonant condition can avoid frequently changing in driver injector operation state which will cause interruptions to users.

The total radiated power $P(\omega)$ produced by electron bunch emitting coherent radiation with the radiated power of a single particle $p(\omega)$ can be written as

$$P(w) = [Ne + Ne(Ne-1)f(w)]\, p(w) \tag{2}$$

where Ne is the number of electrons and f is the form factor describing the longitudinal distribution of particles within a bunch. Ne(Ne-1)f(w)p(w) represents the coherent part of output radiation. The form factor is sensitive to the bunch length. For a typical Gaussian longitudinal distribution electron bunch, form factor is $f(\omega)=\exp(-4\pi^2\sigma^2/\lambda^2)$ with σ denoting the bunch length. Coherent radiation plays the chief role when electron bunch length close to or shorter than the radiation wavelength.

In the PTF, the bunch length at the undulator is less than 1ps, thus high coherent radiation in THz region can be obtained. The superconducting driven injector of PTF is capable to work with high duty factor; generating electron bunches with high repetition rate (see in table 1). This makes THz radiation with high average power also possible. Table 3 shows designed THz radiation parameters of the PTF.

Table 3: Goals for PTF performance

Wavelength	400um ~ 1200um
Optical pulse length	8.00mm ~ 24.00mm
Radiation Angel	0.04 rad
Bandwidth	5%
Peak Power	~100kW
Average Power	~1W
Polarization	linearly polarized

REFERENCES

[1] G. P. Gallerano, S. Biedron. "Overview of Terahertz Radiation Sources." Proceedings of the 2004 FEL Conference, 2004, pp216-221.

[2] F. Zhu, S.W. Chen, F. Jiao, K. Zhao, "Updated design of the DC-SC photo-injector at Peking University." High Power Laser and Particle Beams, 2006, Vol.18: pp. 653-656

[3] J.Billen, PARMELA, LA-UR-96-1835 (1996)