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DESIGN OF THE MULTIPLEXING OPTICAL MEASUREMENT SYSTEM FOR A PRE-BUNCHED THz FREE ELECTRON LASER*

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Abstract

A new and compact a pre-bunched terahertz (THz) free electron laser (FEL) at the National Synchrotron Radiation Laboratory, University of Science and Technology of China is being constructed and aims to generate the tunable radiation frequency ranges from 0.5 THz to 5 THz at 11 - 18 Mev electron energy. This system is expected to use for imaging, basic researches as well as industrial applications as a result of the significant merits of simple, compact and cost-effective. Due to the THz laser measurement system plays an important part in the pre-bunched THz FEL facility. Therefore, a multiplexing THz laser sensing measurement system model is developed for measuring the output laser power and the optical spectrum of THz radiation with the excellent advantages of robustness, high sensitivity and low-cost in this paper.

INTRODUCTION

The configuration overview of the pre-bunched THz FEL [1-3] of the "THz near-field high-flux material physical property test system" is composed of a 3.5 meters length electron linear accelerator whose key design parameters are displayed in Table 1. As shown in Fig. 1, where the pre-bunched THz FEL mainly consists of a photocathode RF-gun, a focusing solenoid, an undulator and a beam dump. It is known that the THz radiation laser are generated by the coherent emission electron pulse train injects to the undulator.

It is seen from Table 1 that the RMS of the beam size is no more than 0.5 mm and the fundamental frequency varies from 0.5 THz to 3.0 THz. The number of the microbunches are 16 which indicates that the total charge is 240 pC. It should be pointed out that the bunching factor is larger than 0.38 and less than 0.64.

Owning to the measured THz radiation only accounts for 10% of the output THz laser, which thereby the parameters for the 10% proportional pre-bunched THz FEL to be measured are listed in Table 2.

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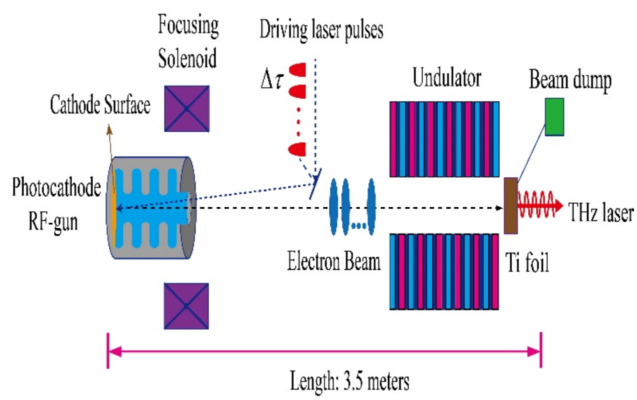

Figure 1: The schematic layout of the pre-bunched THz FEL.

Table 1: The Parameters of the Pre-Bunched THz FEL

Parameters	Values
Electron energy	11−18 Mev
Beam size (RMS)	≤0.5 mm
Microbunches	16
Microbunch charge	15 pC
Fundamental frequency	0.5−3.0 THz
Bunching factor	0.38−0.64

Table 2: The Parameters of the 10% THz Radiation

Parameters	Values
Radiation frequency	0.5−5 THz
Radiation wavelength	60−600 μm
Laser pulse length	10−60 ps
Laser pulse energy	0.1−100 μJ
Repetition frequency	10−50 Hz
Average power of the laser pulse	0.1−500 μW

According to the overall technical requirements and the related parameters of the pre-bunched THz FEL project of the THz near-field high-flux material physical property test system, of which the optical interference measurement system is responsible for commissioning, monitoring and operating the THz radiation laser. Therefore, in which the main characteristic parameters, measurement scenarios and technical indicators corresponding to each subsystem of the THz laser measurement system respectively are given in Table 3.

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Table 3: The Parameter of the THz Laser Measurement System

Parameter	Measured method	Indicator	Value
Laser power	Transmission optical path + Bolometer	resolution	< 1%
Optical spectrum	Transmission optical path + Michelson interferometer + Bolometer	resolution	< 10 GHz

It is emphasized that the data acquisition system of the THz laser measurement system will be developed under the EPICS framework. First of all, the output signal is obtained from the Bolometer detector in the optical power real-time monitoring system based on the data acquisition device. Subsequently, the sampled data is transmitted into the input and output controller (IOC) of the local station whose role is to process the received data and write it into the running database of the EPICS. It is beneficial to any operator interface (OPI) that is connected to the control network can achieve the data of each subsystem of the THz laser measurement from the channel access protocol after obtaining the authorization.

DESIGN OF THE THZ LASER MEASUREMENT SYSTEM

THz Detector

For further choosing the suitable, high-sensitivity and good reliability detector to satisfy the subsequent system requirements and match parameters of THz FEL device, in which the Bolometer detector is considered to be used to this system, as shown in Fig 2.

Figure 2: Bolometer detector.

As compared to other detectors, the sensitivity of the Bolometer detector is sufficiently applicable for responding the radiation wavelength between 60 μm and 600 μm. Correspondingly, where Table 4 introduces the performance parameters of the Bolometer detector which is capable of sufficing the high-sensitivity requirement of the THz laser measurement system.

Table 4: Specifications of the Bolometer Detector (Hi-Res 4.2K Bolometer System)

Parameters	Values
Thermal conductivity G	4 μW/K
Impedance R	14 MΩ
Sensitivity S	6.1×10^{5} V/W
Bandwidth BW	< 200 Hz
Noise equivalent power NEP	4.3×10^{-14} W/Hz$^{1/2}$

Combining with Table 2 and Table 4, we calculated the signal power and the noise power are -14.29-59.69 dBm and 0.61pW respectively corresponding to the signal-to-noise ratio (S/N) is 77.87-151.85 dB in the case of 200 Hz working bandwidth of the Bolometer detector. Obvious that the signal-to-noise ratio is much larger than 1 that is satisfied with our requirements. In next subsection, in which the THz laser interference measurement system model is designed.

THz Measurement System Model

In view of the above performance indicators of the THz laser measurement system, the optical path is designed for monitoring the optical power and spectrum, as described in Fig. 3.

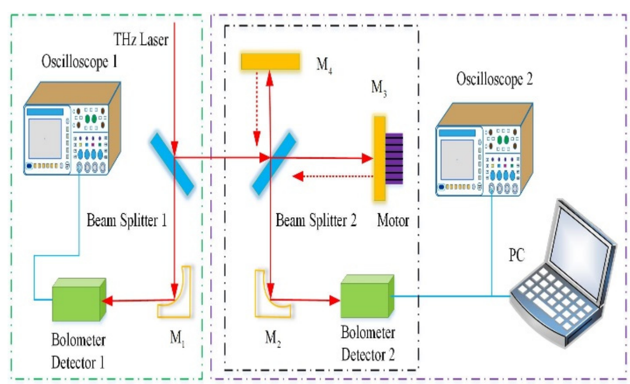

Figure 3: Schematic diagram of the optical path of THz laser measurement system.

As shown in Fig. 3, in which M1 and M2 represent the Off-Axis Parabolic Mirror (OAP), M3 and M4 represent the plane mirror. It is noted that M4 is a fixed mirror whereas M3 is a moveable mirror controlled by the stepper motor in real time, of which are employed to constitute the Michelson interferometer [4-5] along with the beam splitter (BS) and bolometer detector, as marked by the black dashed box. In this system model, the incident laser beam takes up approximately 10% of the THz radiation

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that is split into two parts by the BS and the illuminated on the OAP mirrors of each subsystem respectively. After being reflected by M2 of optical spectrum detection subsystem, the radiation laser pulses are detected by bolometer detector that has the excellent advantages of high sensitivity and relatively good stability. Simultaneously, the responded signal from the bolometer detector is further transmitted into the oscilloscope in real-time observing and extracting data signal.

It is noticed that this THz laser measurement system is a multiplexing measurement system, of which can realize the synchronous measurement of both optical power and output laser spectrum, as marked by the blue and purple virtual box respectively. In this measurement setup, we can monitor the laser intensity accurately with the aid of the oscilloscope and detector. Meanwhile, the optical spectrum is achieved by making use of the PC to carry out the Fourier transform of the sampled signal. For the sake of further validate the proposed designed approach theoretically, which the measured signal intensity [4-5] at the detector can be written as

$$S(\delta) = 2\int \left|RT\right|^2 E(t)E(t+\frac{\delta}{c})dt + 2\int \left|RTE(t)\right|^2 dt \quad (1)$$

Where R and T stand for the reflection and transmission coefficient of the beam splitter respectively, $E(t)$ for the electric field with respect to time t, δ for the optical path difference of the, c for the speed of light in vacuum. The radiation optical spectrum is defined as $I(\omega)$, which can be expressed as equation (2) after the Fourier transformation.

$$I(\omega) = \left|E(\omega)\right|^2 \propto \int_{-\infty}^{+\infty} S(\delta) e^{i\omega\delta/c} d\delta \quad (2)$$

It is apparent that the optical spectrum can be effectively measured by means of the Michelson interferometer and the Fourier transformation. As a consequence, the applicability and reliability of the presented THz laser measurement system are suitable for these demanding requirements.

CONCLUSION

In summary, a Fourier transformation THz laser measurement system model on the basis of the Michelson interferometer is proposed to measure not only the laser output power, but also the optical spectrum of THz FEL system. In addition, we can further optimize the THz system to carry out the offline testing, and improvements and optimization processes have already been underway. Afterwards, we can also make the use of different kinds of interferometers including the Mach-Zehnder interferometer and the Martin-Puplett interferometer to measure the optical spectrum.

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