EXPERIMENTAL RESULTS ON THz SUPERRADIATION FROM THE UNDULATOR IN TSINGHUA UNIVERSITY BEAM LINE*

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Abstract

In this paper, the first operation of a widely-tunable 8-period undulator at terahertz (THz) frequency in Tsinghua University beamline was reported. Superradiate undulator radiation from sub-picosecond electron bunches compressed by chicane was observed. The measured radiation curve shows clearly that the radiation energy is proportional to the charge square, and the THz frequency can be changed from 0.4 THz to 10 THz with narrow-band spectrums. Our results demonstrate a high power and tunable coherent THz source, which could be useful for many applications in the future.

INTRODUCTION

Terahertz radiation have many potential applications in both scientific and engineering areas including biophysics, medical, industrial imaging, nanostructures, and metal science [1,2]. Terahertz sources based on relativistic electrons can provide intense THz radiation of various properties due to the emission mechanisms. Free electron laser (FEL) [3], coherent undulator radiation (CUR) [4], coherent Smith-Purcell radiation [5], coherent transition radiation (CTR) [6], coherent synchrotron radiation (CSR) [7] are typical radiation mechanisms, both narrow-band and wide-band sources included. This paper presents the experimental results on the tunable THz superradiation from the undulator in Tsinghua University beamline.

EXPERIMENTAL DESIGN

The Widely Tunable Undulator

We designed an 8-period widely tunable permanent magnetic planar undulator as shown in Fig. 1 parameters of the undulator is listed in Table 1. According to Halbach's fitting equation, the peak magnetic field is:

$$B_0[\mathrm{T}] = 3.0255 \times e^{-5.2255(\frac{g}{\lambda_u})+1.6202(\frac{g}{\lambda_u})^2}, \quad (1)$$

where g is the magnetic gap and λ_u is the undulator period [8]. The fitted curve of magnetic field and undulator parameter are show in Fig. 2.

Table 1 Parameters of the Undulator

Parameter	Value
Undulator period	100 mm
Number of periods	8
Magnetic gap range	23-75 mm
Peak magnetic field	0.991-0.150 T
Undulator parameter	9.24-1.39

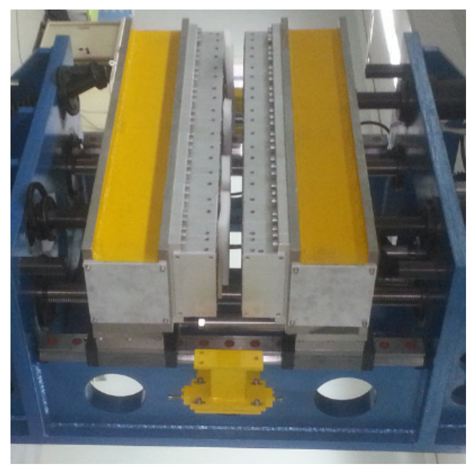

Figure 1: Picture of the tunable permanent magnetic planar undulator.

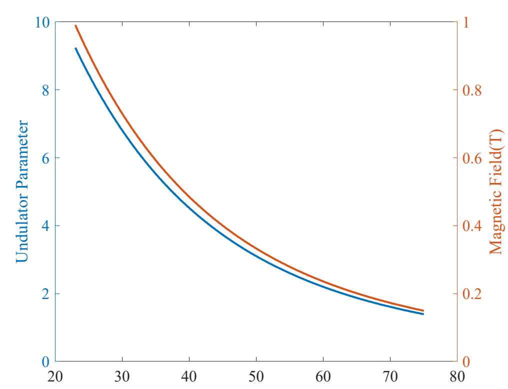

Figure 2: Fitted curve of undulator parameter and magnetic field in the middle plane.

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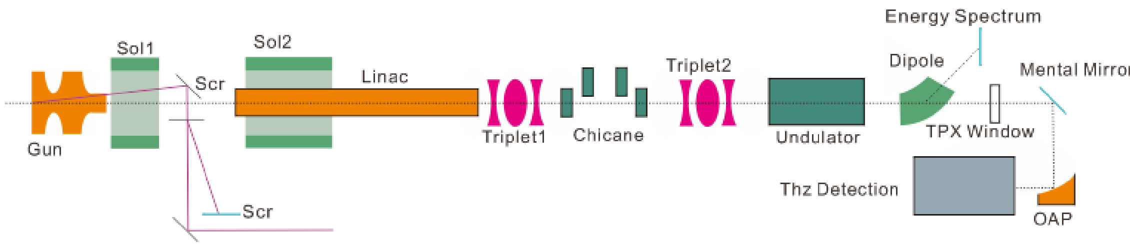

Figure 3: Layout of the Tsinghua beam line and THz system.

The Experimental Layout

The layout of the experiment is shown in Fig. 3. A Ti:sapphire laser system generates ultraviolet driving laser for the BNL/KEK/SHI type 1.6 cell photocathode radio-frequency (RF) gun. The electron bunches are accelerated by a 3 m SLAC-type traveling wave accelerating section. A magnetic chicane is installed to compress the bunch length to tens of femtoseconds [9,10].

The compressed electron beam passes through the undulator and deflected by dipole to the energy spectroscopy. Coherent undulator radiation transmitted through the TPX window and reflected by a metal mirror. The off axis parabolic mirror collected the radiation energy. We used Golay cell detector from Tydex company to detect the total energy and Michelson interferometer to measure the THz radiation spectrum.

EXPERIMENTAL RESULTS

Spectrum Measurement

During the experiment, the electron bunch was accelerated at -45° off the maximum acceleration and compressed by chicane, thus the bunch energy measured by energy spectrum was 28 MeV. The current of chicane was optimized for the radiation energy. Figure 4 shows the autocorrelation curve measured at different undulator gap and the corresponding radiation spectrum is shown in Fig. 5. Central frequency at different gaps is shown in Fig. 6 with the FWHM bandwidth as error bar. The solid line is the frequency predicted by undulator resonant equation:

$$f = \frac{2\gamma^2 c}{\left(1+K^2/2\right)\lambda_u}, \tag{2}$$

where γ is the Lorentz factor, c is the speed of light in vacuum, K and λ_u are undulator parameter and period in Table 1, respectively. The measured radiation central frequency agrees well with the theory. Due to the limitation of Michelson interferometer and sensitivity of Golay cell detector, higher frequency cannot be measured directly. However, it is proper to extrapolate from resonant equation that by changing the undulator magnetic gap and the radiation frequency can be tuned from 0.3 THz up to 10 THz.

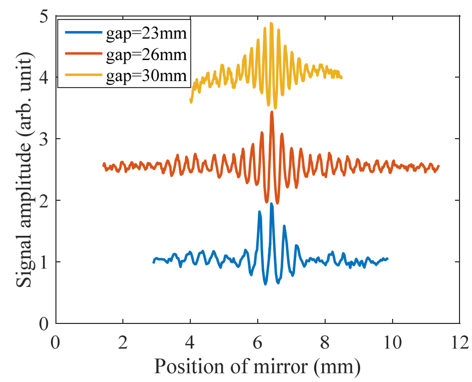

Figure 4: Measured interferogram of coherent THz undulator radiation at different magnetic gap.

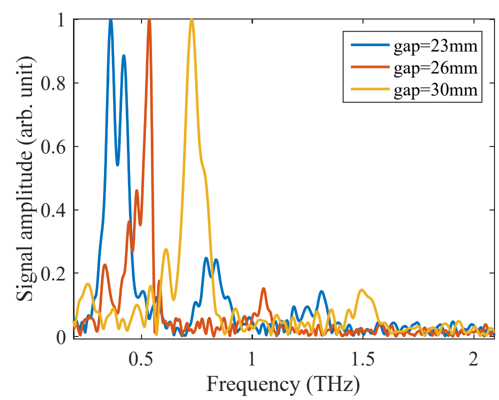

Figure 5: Corresponding radiation spectrum converted from interferogram in Fig. 4.

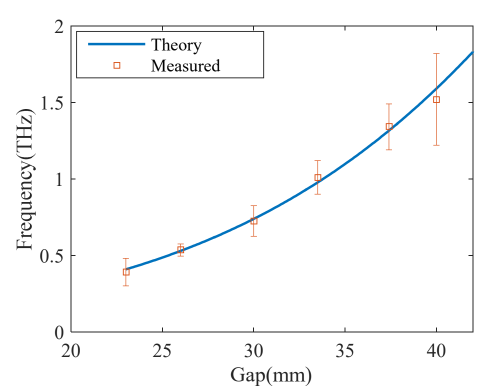

Figure 6: Central radiation spectrum at different gaps.The line is calculated according to the undulator resonant equation and the dots are measured by Michelson interferometer. The error bar is the FWHM bandwidth.

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Radiation Energy Measurement

The total radiation energy was measured by calibrated Golay cell detector. The collection efficiency of the radiation is about 10% and the transmittance of the TPX window is about 60% [11]. According to superradiation theory, the radiation energy scales like the square of the number of electrons and much higher than incoherent radiation [12]. The total energy was measured at constant magnetic gap but with different bunch charge as shown in Fig. 7. The superradiation was confirmed as the cure was quadratic.

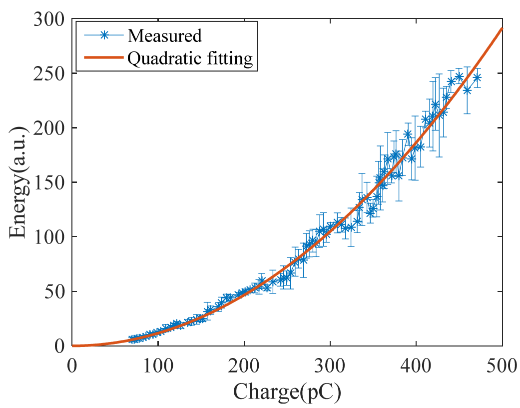

Figure 7: Radiation energy with different bunch charge. The magnetic gap is 38mm.

In Fig. 8, the total radiation energy (the collection efficiency was counted in) was measured when the magnetic gap scanned. The beam energy was 28 MeV and bunch charge was 220 pC. The total radiation energy at 1 THz was more than 10 μJ. With higher bunch charge, the radiation energy would be much larger than 100 μJ at lower frequency and tens of μJ at high frequency.

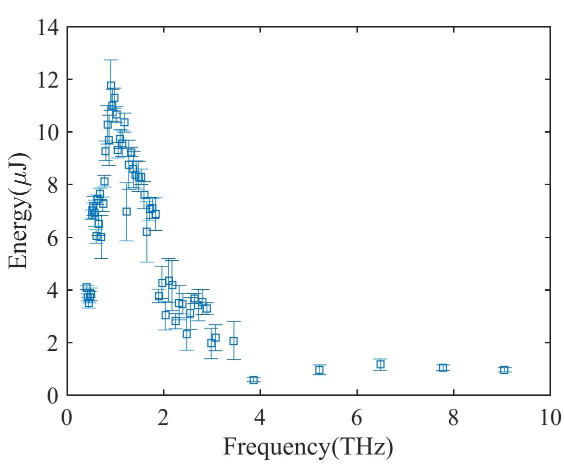

Figure 8: Radiation energy of different central frequency of 220 pC bunch and collection efficiency considered.

CONCLUSION

We report the first operation of a widely-tunable 8-period undulator at terahertz (THz) frequencies at Tsinghua University beamline. The radiation energy can change from 0.4 THz to over 10 THz with narrow spectrum. The pulse radiation energy reaches more than 100 μJ at slightly low frequency and tens of μJ at high frequency, corresponding radiation power up to MW level. The THz source could have applications due to the excellent power and spectrum properties.

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