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The HIGH BRIGHTNESS PHOTO-INJECTOR FOR THz CUR/VUV FEL AT NSRRC

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Abstract

A high brightness photo-injector has been built for THz coherent undulator radiation and VUV free electron laser test facility at NSRRC. In the first phase, the photo-injector was used to produce ultra-short electron bunches for THz CUR generation. The electron beam is generated form a photocathode rf gun followed by a solenoid for emittance compensation. Then A 5.2 m S-band linac accelerates the electron beam and compresses the beam by velocity bunching. Since the beam emittance will grow during the velocity bunching process, a solenoid system was installed to reduce the emmitance growth. Downstream the linac, a quadrupole magnet was use for emittance measurement by quadrupole scan method and the bunch length was measured by the coherent transition radiation. Finally, the ultra-short electron bunch with about few hundreds pico-seconds passes through a U100 planer undulator can produce THz coherent undulator radiation. The instrument setup and results of measurement are presented in this paper.

INTRODUCTION

A THz/VUV free electron laser test facility was proposed at National Synchrotron Radiation Research Center in Taiwan [1]. This machine is designed to operate for tunable coherent radiations in the VUV range with high gain harmonic generation (HGHG) FEL and in the THz range with coherent undulator radiation. A high brightness photo-injector, as shown in Fig. 1, has been built in the Accelerator Test Area at NSRRC [2]. The aim of building this photo-injector is to develop an electron source for VUV free electron laser and THz coherent undulator radiation at NSRRC.

In the first phase, the photo-injector is used to generate ultra-short bunches for THz coherent undulator radiation. A 2 meters long undulator, U100, is installed after the photo-injector for THz CUR experiment. The undulator has 18 periods and the period length is 100mm. We want to get a 90 fs short bunch beam with 100 pC by means of velocity bunching while the gradient of the linac should be 15 MV/m in order to compress the bunch as short as possible.

THE PHOTO-INJECTOR SYSTEM

The electron source of the photo-injector is a laser-driven photocathode RF gun with Cu cathode. The photocathode gun is 1.6 cell BNL type cavity. The resonant frequency of the gun is tuned by controlling the temperature of the cavity. The resonant frequency of the gun is 2998.05 MHz when the cavity works at 55 °C. The coupling coefficient of the gun is 0.7. When the RF input power is 4.15MW, the peak field at the cathode can achieve 60 MV/m. At this condition, the max beam energy after the gun is 2.8 MeV.

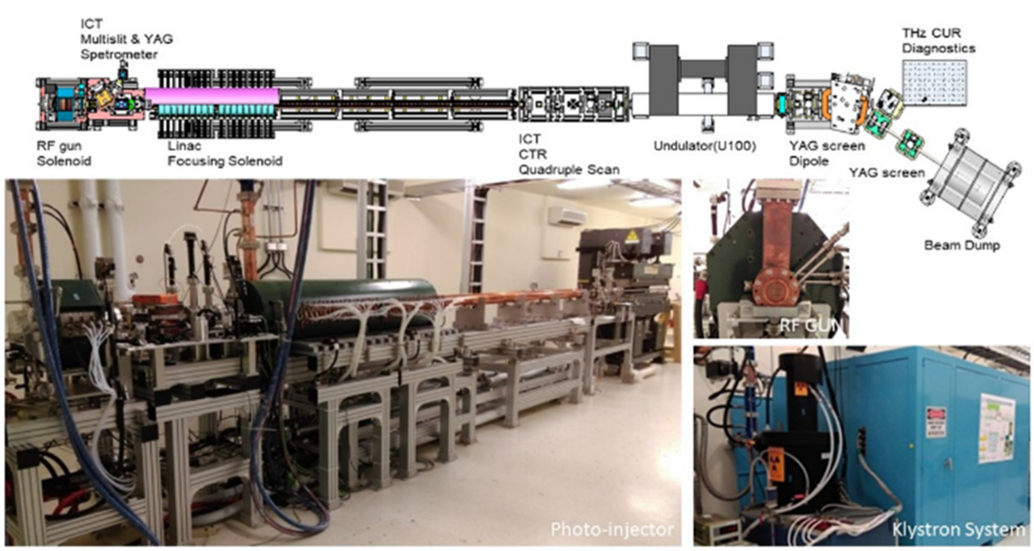

Figure 1: Layout and pictures of the photo-injector at NSRRC.

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The rf system consists a Thales TH2100A klystron and a home-made modulator which power the klystron. A klystron from Thales can provide 35 MW rf power. The rf power is split into two parts by a power divider. 5MW is delivered to the gun and other is delivered to the linac. A phase shifter was installed between the power divider a for controlling the rf phase. The linac of the photo-injector is a 5.2 m long constant gradient structure. This structure is similar to the DESY LINAC-II design. The linac was not equipped with focusing solenoids initially. In order to focus the beam size during the velocity bunching process, we made a solenoid to focus the beam. This solenoid has 2 sections of coils. Each section is composed by 9 sets of coils. The length of one section is 90 cm. An iron plates are inserted in each set for field straightening. Outside the solenoid, there is an iron shield (high μ metal) to prevent the leakage of magnetic field.

The ultrafast laser system is a Ti:sapphire laser system based on the chirped-pulse amplification technique. This system consists of an oscillator, an amplifier, a third harmonic generator. After the THG and the UV stretcher, the UV laser pulse with 280 uJ is used to drive the photocathode gun.The pulsed width of the UV laser can be stretched from 800 fs to 10 ps by a UV stretcher. At the exit of the stretcher, the maximum laser energy is 280 mJ. After propagating about 35 m long to the cathode, the maximum energy is 177uJ. In order to monitor the laser profile and pointing stability on the cathode, a CCD is located such that the optical path length to the cathode and the CCD are equal. The clear aperture of the laser beam is about 2.5 mm. We also use this CCD to record the pointing stability. The laser pointing stability on the cathode is 8.5 μrad. It caused 250 μm horizontal drift and 210 μm vertical drift.

MEASUREMENT

To check the performance of the photo-injector, we measured the beam pointing stability and the transverse emittance. The beam pointing stability was observed by a YAG screen. The horizontal beam drift after the linac is about 45um rms. The vertical beam drift is about 57 um rms. We measured the transverse emittance by the quadruple scan method. By using the quadrupole scan technique for the beam emittance measurement, the quadrupole downstream the linac is used to converge the beam at the YAG screen. The bam size at the YAG screen can be written in terms of quadrupole focal length or strength as:

$$\sigma_{s,11} = D^2(kL)^2 + (-2D\sigma_{q,11} - 2D^2\sigma_{q,12})(kL) + (\sigma_{q,11} + 2D\sigma_{q,12} + D^2\sigma_{q,22}) \quad (1)$$

While $\sigma_{s,i}$ and $\sigma_{q,i}$ are the beam matrix at the quadrupole and screen, respectively. The quadrupole strength is k, the effective quadrupole length is L and D is the drift from the center of the quadrupole to the screen. The equation (1) shows that the beam size on the screen, $\sigma_{s,11}$ is a quadratic function of quadrupole strength k. We can fit the beam size with a quadratic equation, $ax^2 + bx + c$, so the beam matrix at the quadrupole is determined by :

$$\sigma_{q,11} = \frac{a}{D^2} \quad (2)$$

$$\sigma_{q,12} = \frac{-2D\sigma_{q,11} - b}{2D^2} \quad (3)$$

$$\sigma_{q,22} = \frac{c - \sigma_{q,11} - 2D\sigma_{q,12}}{2D^2} \quad (4)$$

The emittance can be calculated by using the beam matrix:

$$\varepsilon = \sqrt{\sigma_{q,11}\sigma_{q,22} - \sigma_{q,12}{}^2} \quad (5)$$

The beam size $\sigma_{s,11}$ in eq. (1) is a function of the quadrupole strength. With a quadratic fitting, all the coefficient a, b and c can be determined as discussed above. From eq. (1) to (4) the beam matrix at the quadrupole are obtained. Finally, beam parameters of emittance and Twiss functions are determined. The quadruple is located at 0.855 m from the YAG screen. The quadrupole strengths are varied while observing the beam size at a YAG screen. The image from the YAG screen is recorded by a CCD camera. For this emittance measurement, the electron beam is delivered at a 10 Hz rate with an energy of 62 MeV and 250 pc. Fig.2 (a) shows quadratic curve of the beam size as a quadratic function of the quatrupole strength with coefficients, a=7.937×10-8, b=-2.741×10-7 and c= 2.81×10-7. The emittance measured at different gun solenoid field. While the solenoid field is 1316 gauss, the minimum normalized emittance is 10 mm-mrad which is shown in the Fig.2 (b).

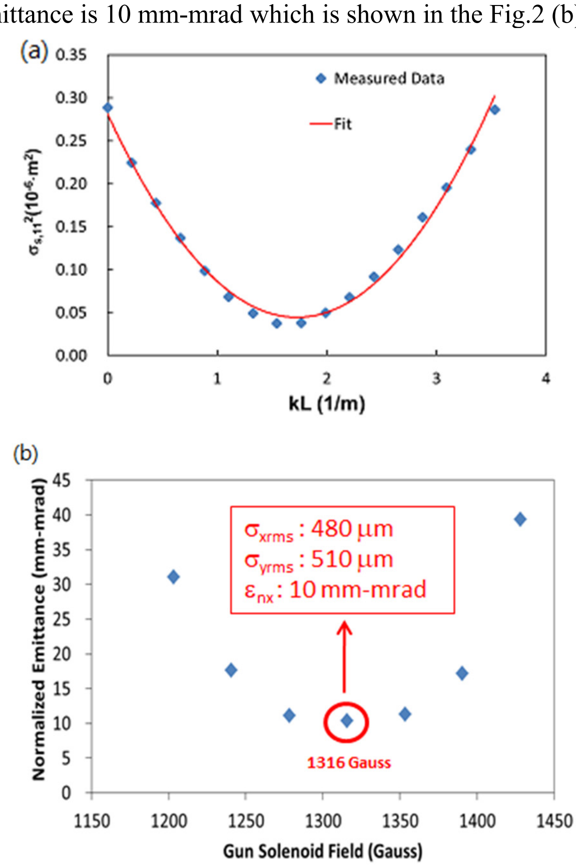

Figure 2: (a) Quadrupole scan for normalized transverse emittance measurement. (b) Normalized transverse emittance measured at different gun solenoid field.

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The bunch length was measured by coherent transition radiation (CTR). The setup of the CTR measurement is shown in Fig.3. A 20-mm diameter aluminum foil placed at 45º in the beam path was used as a CTR radiator. The backward transition radiation from the foil is emitted perpendicular to the beam axis and exits the beam line vacuum through a THz window at normal incidence. The transition radiation is collected and collimated by a gold plated 90° off-axis parabolic mirror with 15 cm focal length. Then the CTR is further transported to the THz diagnostics station by another gold plated mirror. The aluminum foil and the YAG screen are mounted on the same motorized linear motion feed-through. By moving the feed-through to different positions, the YAG screen or the aluminum foil is moved to the beam axis and the beam status or the CTR signal can be observed.

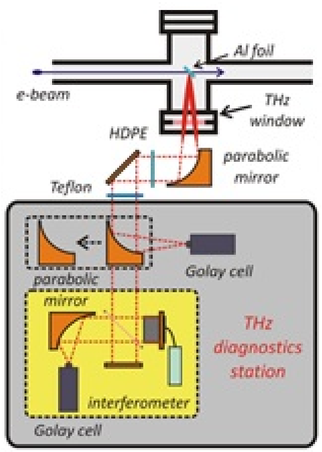

Figure 3: Setup of the CTR measurement.

The collimated THz radiation is transported into a THz diagnostics station built for characterizing the THz signal. In order to prevent the power loss of THz radiation in air, the station is purged with dry air. While the THz radiation is incident into the station, an off-axis parabolic mirror with a 15 cm focal length mounted on a translation stage is used to focus the signal onto a Golay cell detector to measure the THz power. Once the parabolic mirror is moved away, the THz radiation travels into a Michelson-Morley interferometer system for power spectrum measurement. The interferogram of the recombined signal coming from two optical arms is detected by another Golay cell detector. The measured result is shown in the Fig.4. With this information the THz spectrum and the information of the bunch length can be found.

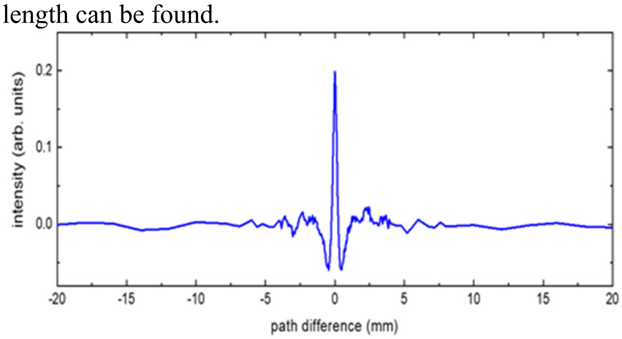

Figure 4: Measured interferogram of the CTR.

The electron beam is delivered at a 10 Hz rate with an energy of 17.7 MeV and 210 pC. One interferometer arm length is changed by a linear motor stage controlled by a computer. The motion step size is set at 20 µm, corresponding to a time delay 140 fs. To find the best compression condition, the injection phase of the electron beam is varied for bunch length measurement. Figure 5 shows the bunch length measured at different linac injection phase. Assuming that the electron bunch is the Gaussian distribution, the minimum measured FWHM for the bunch is 346 µm and the bunch length is estimated to be 490 fs rms.

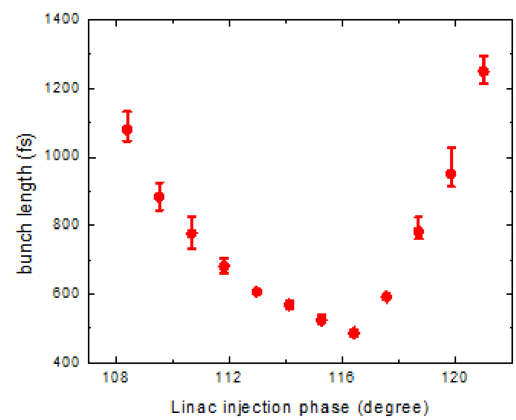

Figure 5: Bunch length measured at different linac injection phase.

CONCLUSION

The photo- injector system for the THz/VUV FEL has been built at NSRRC. Transverse beam emittance of the electron bunch generated from the injector has been measured using quadrupole scan method. The normalized horizontal beam emittance of the electron beam at the end of the injector is 10 mm-mrad. Our goal is to generate electron beams with normalized emittance lower than 3 mm-mrad. To achieve this goal, making a laser pulse with flattop longitudinal profile by pulse stacking method will be used to reduce the emittance. Coherent transition radiation interferometry was used to measure the length of the ultra-short bunches produced by the velocity bunching. The results show that the bunches are 490 fs FWHM. Since the electron energy is only 17.7 MeV while accelerating gradient of the linac is only 11.5 MV/m, the bunch can not be compressed the design value of 95 fs. The next step, we will upgrade the klystron system in order to deliver more power to the linac to increase the accelerating gradient.

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