Electron Beam Generation by a Photocathode RF-gun at Kyoto University

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Abstract

A 1.6 cell S-band BNL type photocathode RF-gun has been installed for a compact seeded terahertz (THz) free-electron laser (FEL) amplifier system at Institute of Advanced Energy, Kyoto University. The RF-gun is used for generating an ultra-short, intense and low emittance electron beam suitable for a THz radiation generation by a short planar undulator. The photocathode plug is exchangeable by a load lock system and illuminated by a UV laser with the wavelength of 266 nm. In the initial stage, the RF conditioning, the performance test and the measurements of electron beam properties was performed with using the copper cathode. The detailed of the RF-gun, test and measurement results will be presented in this contribution.

INTRODUCTION

A photocathode RF-gun is well known as a one of the best electron sources with many advantages. The photocathode RF-gun is able to produce an electron beam with a high-intensity, short-pulse, and low-emittance. This gun is also completely free from the backbombardment effect [1] that allows higher bunch charge and longer macro-pulse duration. The spatial and temporal electron distribution can be manipulated by controlling the laser distribution. By these outstanding features, the photocathode RF-guns are suitable for a free-electron laser system and widely used in many advance accelerator systems.

A 1.6-cell photocathode RF-gun has been installed as a new electron source and will be used for a compact seeded terahertz free-electron laser (THz-FEL) system at Institute of Advanced Energy, Kyoto University. The target radiation wavelength of this system is from 300 to 800 μm which extend the radiation range of the current mid-infrared free electron laser (MIR-FEL) [2]. The system also installed in the same accelerator room of MIR-FEL. The schematic diagram of the compact seeded THz FEL system is shown in Fig.1.

The installation of the photocathode RF-gun had been started since the end of year 2013. Then, the installation of photocathode RF gun was completed and the photoelectron from the gun was successfully generated in the end of May 2015. The beam diagnostic system was set up and beam properties have been measured. The details of the photocathode RF gun system, measurement set up and results are explained in this proceedings.

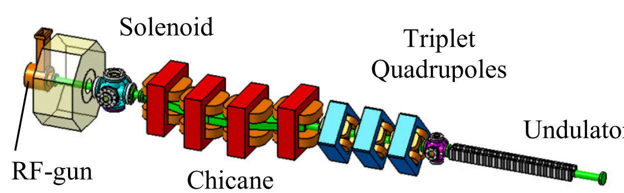

Figure 1: Schematic view of the compact THz-FEL at Institute of Advanced Energy, Kyoto University.

PHOTOCATHODE RF-GUN SYSTEM

The photocathode RF-gun system for the compact seeded THz-FEL is mainly composed of an emittance compensation solenoid magnet, the RF-gun cavity, a load-lock system, a laser port, vacuum components and an evaporation chamber. The photocathode plug can be exchange by the load-lock system attached to the gun backplane. This system allow to exchange and transport the plug without breaking the vacuum condition. Two ionization pump and two non-evaporative getter (NEG) pump are used and provide the total pumping capacity of 380 L/s. In this study, a copper cathode was used for the conditioning of the gun cavity and the beam property measurements. The cut view of the photocathode RF-gun system is shown in Fig.2.

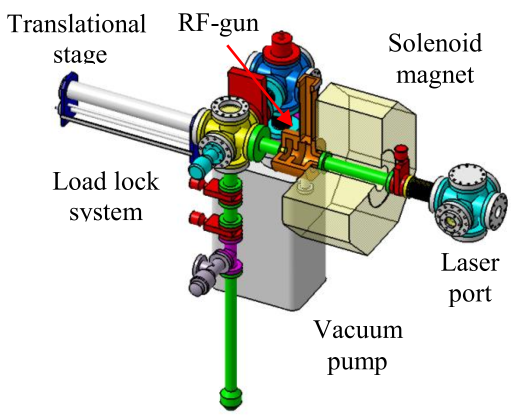

Figure 2: Cut view of the photocathode RF-gun system.

Photocathode RF-gun

The 1.6-cell S-band BNL-type photocathode RF-gun is the improved model of KEK and was manufactured in 2008 [3]. This gun has been tested and succeeded in generation of high brightness electron beam. The RF-gun performances have been studied by numerical simulations in [4]. The conditioning of the cavity was performed with the RF pulse duration of 2 μsec and the RF repetition rate of 10 Hz. The vacuum pressure and temperature of the gun was a few 10^{-8} Pa and 30 °C, respectively.

Laser system

The photocathode RF gun is driven by a UV laser with the wavelength of 266 nm [5]. The laser system consists of a mode-locked Nd:YVO_4 oscillator, a beam alignment control, two amplifiers and two non-linear crystals (SHG and FHG). The oscillator provides lasers at the wavelength of 1064 nm with the repetition frequency of 89.25 MHz and the pulse duration of 7.5 ps at the full width at half maximum (FWHM). The beam alignment feedback control is used for the beam position and angle stabilization. After that, the lasers are amplified by the two laser diode pumped amplifiers. Finally, the pair of non-linear crystals (SHG, FHG) converts the fundamental wavelength into the fourth harmonic wavelength at 266 nm. The laser beam is transported to the gun by several UV enhanced aluminium mirrors. The efficiency of the optical transportation was measured to be 82-92%.

RF system

The photocathode RF-gun shares the RF power source with the existing 4.5 cells thermionic cathode RF-gun of the MIR-FEL. This RF source has the peak power of 10 MW and the repetition rate of 10 Hz. The waveguide RF switch, which is installed downstream the circulator, is used for switching the RF power between these two RF-guns. The phase different between the RF and laser system can be adjusted by the electronics phase shifter or the manual phase shifter. The block diagram of the RF and laser system is shown in Fig. 3.

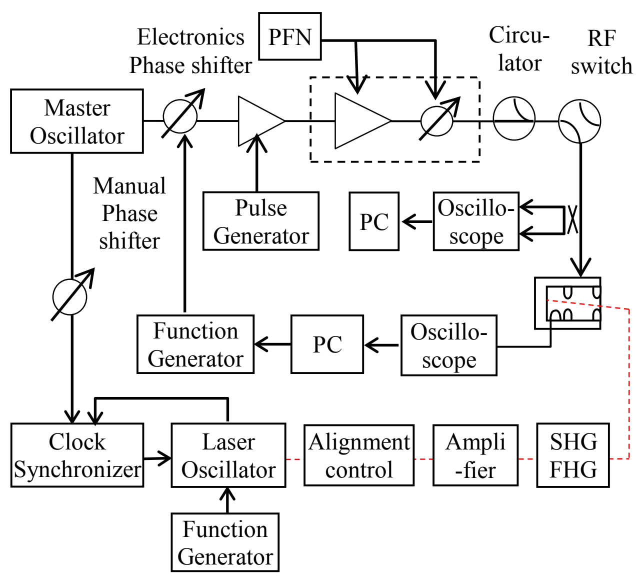

Figure 3: Block diagram of the RF and laser system for the photocathode RF-gun.

MEASUREMENT AND RESULTS

To investigate the beam properties, we have set up the beam diagnostic system consisted of a triplet quadrupole magnet, a bending magnet, a steering magnet, a Faraday cup, an extracting window, two fluorescence screens and two CCD cameras. The schematic diagram of the beam diagnostic system is shown in Fig.4. The images of dark current and first photoelectron of the focused beam on screen no.1 are shown in Fig. 5.

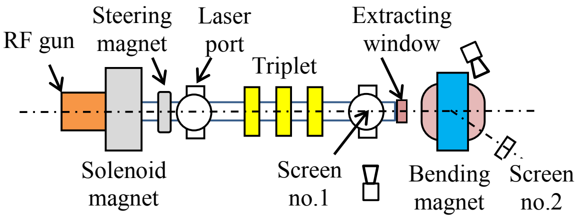

Figure 4: Schematic diagram of the beam diagnostic system for the photocathode RF-gun (top view).

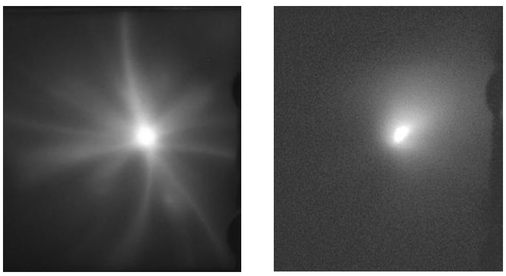

Figure 5: Images of the dark current (left) and the first photoelectron (right) of the focused beam on the screen no.1.

Bunch Charge and Dark Current

Bunch charge was measured by the carbon Faraday cup placed out of vacuum and next to the beam extracting window which is made from an aluminum coated polyimide film with thickness of 8 micron. The input RF power and the solenoid magnetic field gradient were set at 8.6 MW and 1926 G, respectively. The laser was injected with a single pulse. The measured bunch charge versus the laser injection phases at different laser energies are shown in Fig. 6. The bunch charge increase proportionally until peak at the laser injection phase around 70 to 80 deg. Then, the bunch charge decrease rapidly at the laser injection phase over 80 deg. Because some electrons were not accelerated due to the RF deceleration phase. Fig. 7 shows the dark current as a function of the solenoid magnetic field at the input RF power of 9.1 MW. The maximum dark current is 70 pC at the solenoid magnetic field of 1779 G.

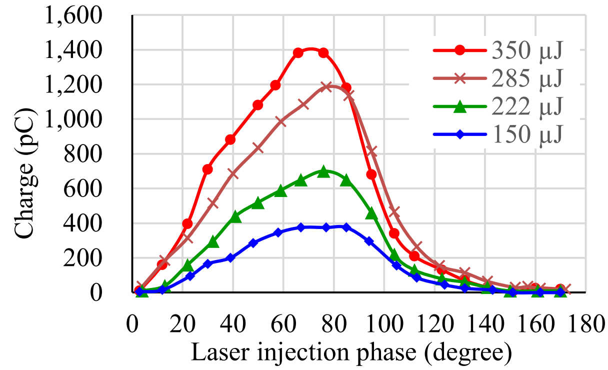

Figure 6: Bunch charge as a function of the laser injection phase at the different laser pulse energy.

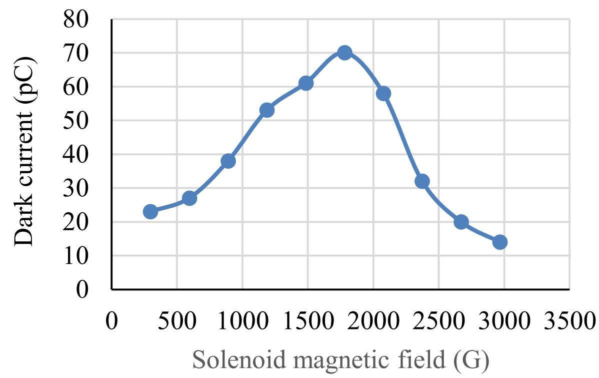

Figure 7: Dark current as a function of the solenoid magnet field at the input RF power of 9.1 MW.

Beam Energy

The rectangular bending magnet was used as an energy spectrometer. The magnet has the thickness of 65 mm, and the pole gap of 30 mm. The screen no.2 is placed behind the bending magnet with the distance from the magnet yoke of 100 mm and offset from the beam center of 60 mm. The center of bended beams on the screen was observed by the CCD camera. The laser energy was set at 180 μJ per three pulse to get clear image on the screen. The solenoid magnet was adjusted to obtain a focused beam on screen no.2. The dipole magnet current as a function of laser injection phase is shown in Fig. 8. Then, the beam energy was determined by comparing the beam trajectory with the simulation result. It should be noted that the measured energy should be lower than actual accelerated energy because of the energy loss by the extracting window and air. The beam energy at the input RF power of 9.1 MW is shown in Fig. 9.

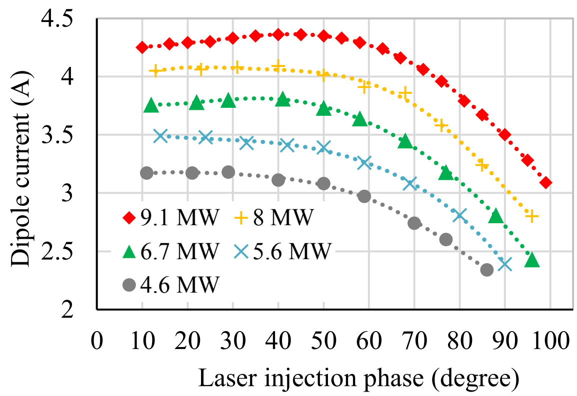

Figure 8: Dipole current as a function of the laser injection phases at the different input RF power.

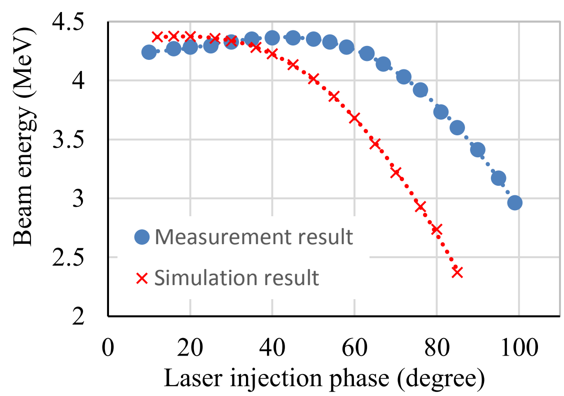

Figure 9: Simulation (cross mark) and measurement (circle mark) results of the beam energy at the input RF power of 9.1 MW as a function of the laser injection phase.

From the Fig. 8, the beam energy is nearly constant at the low laser injection phase, while the beam energy decrease rapidly at the high laser injection phase. From Fig. 9, the simulation result of the RF gun with accelerating gradient of 50 MV/m has not good agreement with the measurement result. It may cause by accelerating field ratio between the full- and half-cell of the RF-gun of the simulation and the actual one are different. The further study of the numerical simulation model is needed.

Transverse Emittance

Transverse beam emittance was measured by a quadrupole scan technique. The last magnet of the triplet which has the effective length of 55 mm was used for the measurement. The distance from center of the magnet to the screen no.1 is 140 mm and from the cathode surface to the screen no.1 is 1275 mm. The images on the screen no.1 were captured by a CCD camera. Then, the beam sizes were calculated. The unnormalized rms emittance as a function of the solenoid magnet current and the laser energy is shown in Fig. 10 and 11, respectively.

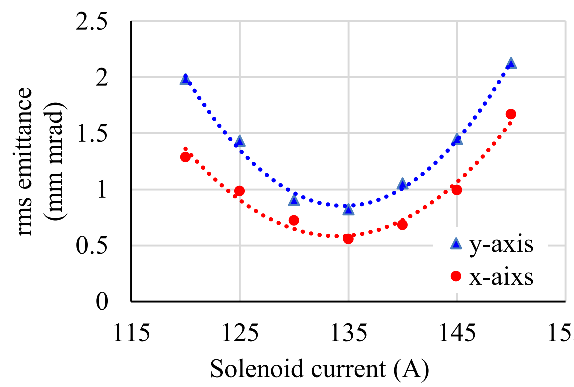

Figure 10: Unnormalized rms emittance as a function of the solenoid magnet current at the bunch charge of 53 pC and the injection phase of 40 deg.

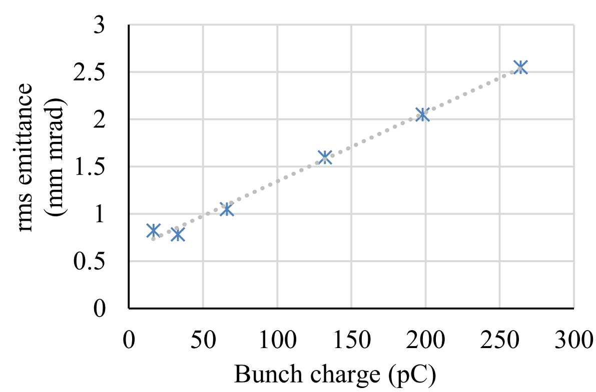

Figure 11: Unnormalized rms emittance as a function of the laser energy at the solenoid gradient of 1926 G and the laser injection phase of 40 deg.

CONCLUSION

A 1.6-cell photocathode RF gun has been installed at the Institute of Advanced Energy, Kyoto University. The photocathode RF gun successfully generated the photoelectron with the maximum measured beam energy around 4.4 MeV at the input RF power of 9.1 MW. The bunch charge can reach up to 1.4 nC at the laser injection phase around 70 degree and the laser energy of 350 μJ. The unnormalized rms emittance at the bunch charge of 53 pC is lower than 1 mm mrad in both horizontal and vertical.

For the further study, we will measure a precise beam energy by in vacuum measurement in the chicane section. The numerical simulation model also will be investigated in order to have a better understanding of the cavity condition.

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