Performance Test of a Photocathode RF Gun

Fumio SAKAI, Jinfeng YANG, Masafumi YOROZU, Yasuhiro OKADA, Akira TSUNEMI, Yasushi AOKI, Akira ENDO, Takahiro KOZAWA*, Youichi YOSHIDA*, Tamotsu YAMAMOTO*, Seiichi TAGAWA*
Sumitomo Heavy Industries, Ltd (SHI)
2-1-1 Yatochou, Tanashi-shi, Tokyo, 188-8585, Japan
*The Institute of Scientific and Industrial Research, Osaka University
8-1, Mihogaoka, Ibaraki, Osaka, 567-0047, Japan

Abstract

A photocathode RF gun for the high duty operation was developed by a BNL/KEK/SHI collaboration and operated at the linac facility of the University of Tokyo, successfully. On the basis of this design, we constructed a gun system and performed preliminary experiments at ISIR of Osaka University. The experiments were performed using S-band RF of 1.5MW peak power. The quantum efficiency of electron emission was obtained to be 10^{-5}.

1 Introduction

High brightness electron with low emittance and short bunch length is expected interesting to apply to new technologies, such as FEL, laser acceleration, generation of short X ray pulse by Compton scattering, and so on. The photocathode RF gun being capable of high duty operations was developed by BNL/KEK/Sumitomo heavy Industries, Ltd (SHI) collaboration as a source of high brightness electron bunches [1]. On the other hand, a stable picosecond laser illuminating the cathode is a key component to obtain a stable electron generation. Our group has developed a laser diode (LD) pumped picosecond laser by a joint project with Time-Bandwidth Product, Ltd.[2].

For a preliminary experiment, the photocathode RF gun and the picosecond laser were installed at the Institute of Scientific and Industrial Research of Osaka University [3]. The photocathode RF gun was set instead of a thermal gun and connected to three linacs accelerating electrons up to 120MeV. We report the fundamental characteristics of electron bunch from the photocathode RF gun and linacs.

2 Experimental apparatus

The photocathode RF gun system consists of the gun with a Cu cathode, dipole magnets, and a solenoid magnet. The LD pumped picosecond laser for illuminating cathode was set to the side of the gun. Laser light was transported with a mirror system. The gun system was connected to linacs by a beam transport system with the magnets and beam diagnostic equipment. The whole system is shown in Fig.1.

2.1 Photocathode RF gun

The 1.6 cell photocathode RF gun has a Cu cathode, which has a long lifetime. Although Quantum efficiency (QE) of the Cu cathode is low (10^{-4}), laser energy is increased to get 1nC charge per bunch. For high duty operation, the gun has three cooling channels to remove the RF heating and control the temperature of the gun within

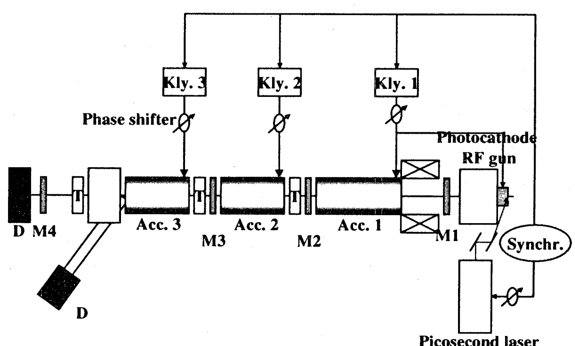

Figure.1 Experimental system. M1-4: Charge and screen monitor, T: Quadrupole Magnet, B: Bending Magnet, D: Dump

0.1 degree. The design condition of RF input is 6MW-peak power with 4 μs duration and 50Hz-repetition rate. However, the RF pulse of 1.5 MW peak-power with 3μs FWHM duration was used in this experiment. The repetition rate was 10Hz.

2.2 Picosecond Laser for the Photocathode RF gun

The all solid LD-pumped Nd: YAG laser consists of a passive mode-locked oscillator with a semiconductor saturable absorber mirror (SESAM), a regenerative amplifier and a power amplifier. The frequency of the oscillator is 119 MHz being to equal to 1/24 of 2856 MHz S-band radio frequency. A timing stabilizer measures the phase and the frequency offset between the laser pulses, which is detected by a photo-diode, and the reference 119MHz RF signal, and adjusts the cavity length of the oscillator to maintain the constant phase relation between the two signals. Pulses from the oscillator are picked up by a Pockels Cell. The regenerative amplifier is operated with 1-100Hz repetition rate. The 1064nm fundamental with about 2mJ pulse energy is quadrupled to 266nm UV radiation with about 100μJ pulse energy by two non-linear crystals. The stability of system, such as timing jitter, energy fluctuation and pointing stability is very important for the photocathode RF gun. The specifications of the laser are shown in Table 1. UV light from the laser was transported by the mirror system and injected to the cathode at oblique angle. The laser beam position on the cathode was adjusted by a remote controlled mirror.

Table 1 Specifications of the laser

Laser material	Nd:YAG
wavelength	266nm (4th harmonics)
Pulse duration	23ps @1064nm
Pulse energy	100μJ/pulse@266nm
Repetition rate	1-100Hz
Energy stability	<2%
Timing jitter	<0.5ps

2.3 Synchronisation system

A block diagram of the synchronisation system for operation of the gun is shown in Fig.2. A master oscillator supplies 119 MHz radio frequency. This RF signal is divided into two. One drives the oscillator laser. The other is multiplied in frequency by 24 to 2856MHz, to drive the gun and the accelerator. A synchroniser in the laser generates a trigger for a Pockels Cell. As a result, the 10Hz laser outputs synchronised with the RF fields for electron accelerator the accelerators are obtained. A phase shifter is used to adjust the laser injection phase. The timing jitter between the master oscillator and laser output is controlled within 0.5 ps by a timing stabiliser. However, the timing jitter between the laser outputs and 2856MHz RF fields increases actually by the other sources a frequency multiplier, Klystron, and the change of circumstances.

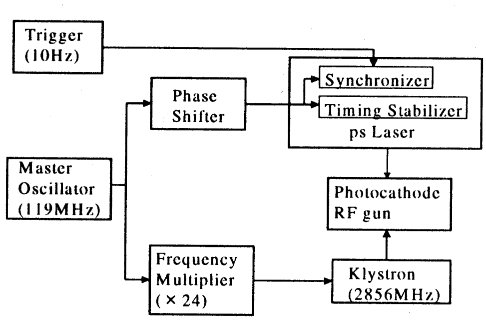

Figure.2 Block diagram of the synchronisation system

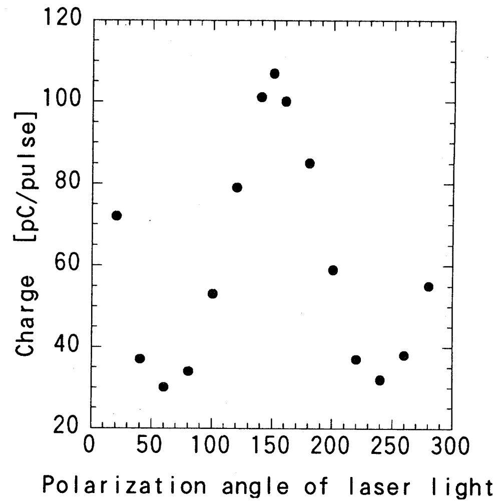

Figure.3 Bunch charge vs. Polarization angle. The angle with the maximum charge is correspondent to P-polarization.

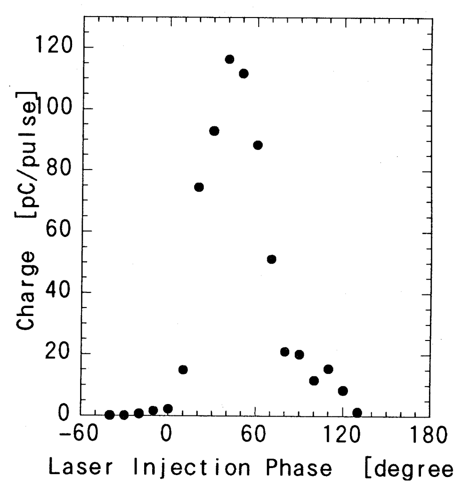

Figure.4 Emission bunch charge vs. laser injection phase. The zero point is set at charge zero phase which corresponds to the zero axial field.

3 Experimental results

3.1 Electron emission

The yield of electron emission is a key factor for applications of electron pulses. Laser light was injected with the oblique angle, so QE was dependent on the polarization of light [4]. The electron charge was measured as a function of the direction of the polarization using by a half wave polarizer. A Faraday cup was set at about 1m from the cathode. Current of solenoid magnet was adjusted to get maximum charge. The relation between the polarization and the electron charge is shown in Fig.3. The maximum electron charge was obtained at the P-polarization being correspondent to the maximum energy absorption by the cathode. QE dependence on the laser injection phase was measured under the fixed polarization and the current of the solenoid. The zero degree of the injection phase is determined at the onset of the current, which corresponds to the zero field at the cathode. In Fig.4, it can be seen that the maximum electron charge was obtained to be 115ps at the 40degree. When the laser pulse energy with 266nm was 65μJ, QE was 8×10^{-6}. This QE is about 1/20 of the reported value for the same structural gun [5].

The emission charge from the cathode should be maximum at 90 degree, because the surface field on the cathode is maximum. However, the electrons emitted at 90 degree have lower energy and high energy-dispersion, so the collection efficiency at the Faraday cup should be low. If higher RF power is supplied to the gun, the higher electron charge enhanced by Schottky effect [6] is obtained at near 90 degree.

3.2 Electron energy from the gun

Energy of electron emitted from the cathode was measured with a dipole magnet and a beam profiler at the downstream of the gun. The measured electron energy versus laser injection phase is shown in Fig.5. The maximum energy was obtained from 10 to 40 degree. The field gradient estimated from the energy data is about 35MV/m.

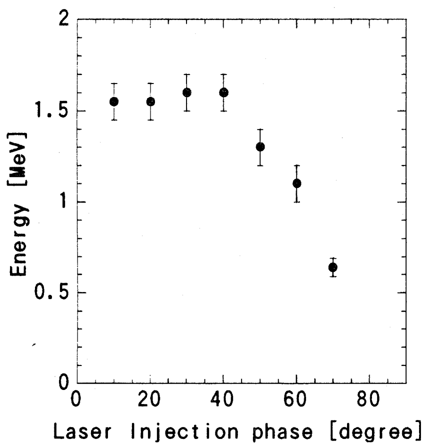

Figure.5 Electron energy from the gun

3.2 Beam acceleration and emittance

Electron bunches from the gun were accelerated to 117MeV with 1.2% energy dispersion by three linacs. Transmittance through the three linacs was about 30%. The low transmittance was due to misalignment, because it was difficult to adjust electron beams with the low field magnet designed for a thermal cathode gun.

Emittance was measured at the downstream of linacs by the standard quadrupole scan technique. The relation between the square of beam diameter on a phosphor screen and the current of a quadrupole magnet is shown in Fig.6. The normalised RMS emittance was 0.6 πmm-mrad. Laser injection phase was 40 degree, and the magnetic field of the solenoid magnet was 0.8 kG, which were determined to obtain the maximum transmittance. The charges at the gun exit and at the downstream of linac were 90pC and 30pC, respectively. Low emittance was obtained due to the reduced space charge effect of low transmittance beam. We also measured the emittance with other conditions, other magnetic field of the solenoid magnet and the other laser injection phase. The emittance ranged from 0.4 to 0.8 πmm-mrad, however, the transmittance was changed under each condition. As a result, the dependence of emittance on these parameters was not analyzed in detail.

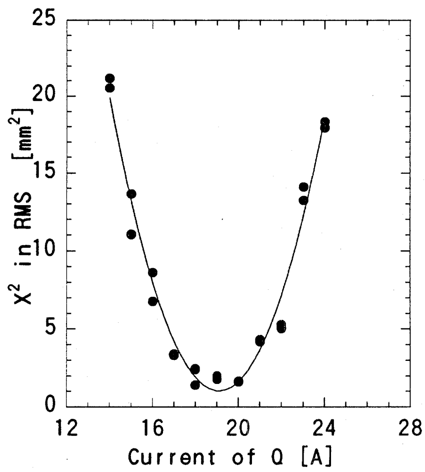

Figure 6 Square of beam diameter vs. Current of a quadrupole magnet. Solid line: Least square fitting with the 2nd order polynomial.

4 Conclusion

The preliminary experiments using the photocathode RF gun and the stable picosecond laser were performed. Although RF power was low and RF conditioning time was not enough, QE was measured to be about 10^{-5}. The normalised emittance was obtained to be 0.6 πmm-mrad.

We start to construct the acceleration system up to 10 MeV in our facility to demonstrate the X-ray generation by Compton scattering. The performance of the gun with 50Hz high duty operation and the stability of electron bunches, such as timing jitter and pointing stability will be measured.

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5 Reference

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