EXPERIMENTAL RESULTS OF A PHOTOCATHODE RF GUN DRIVEN BY A STABILIZED ALL-SOLID PS LASER

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Abstract

A stable and high brightness electron source using a photocathode RF gun was installed in our laboratory to generate ultra-short X-ray pulses by Compton scattering. Commissioning tests were performed and high quality 12MeV electron bunches were obtained.

1 INTRODUCTION

Very short pulse X-ray is a very useful tool for studying dynamics in physics process, chemical reactions and biological process. Some researchers have been studied the short pulse X-ray generation[1,2,3] by Compton scattering, which has some advantages, monochromaticity, easiness of energy tuning, low divergence from a small equipment. To generate high brightness X-ray efficiently, there are some key technologies, namely generation of highly bright electron bunches, high power femtosecond laser and stability between electron bunch and laser light in space and temporal domain. In the last five years, our group has been developing the technologies of the stable generation of high brightness electron bunches, photocathode RF gun[4] and a stable all-solid-state picosecond laser for the photocathode[5]. An electron accelerating system including the photocathode RF gun and a linac was installed in the beginning of this year. The commissioning tests of the electron system were performed successfully. This paper discusses the design of the electron accelerating system, and the first results of the test and a plan of the generation of the Compton X-ray beam.

2 APPARATUS

The whole system is shown in fig.1. This system is composed of an acceleration section with the gun and the linac, a beam transport and interaction section and the x-ray detection section. Electron bunches are generated and accelerated up to 12MeV by the photocathode RF gun and the linac. Electron bunches are focused in the Compton chamber and interacted with femtosecond laser light. Then, electron bunches are bent and stopped at a beam dumper and X-ray is measured by X-ray detectors. To avoid the fluctuation due to thermal effects, temperature of cooling water for the gun, the linac, high power supply including a Klystron and magnets are controlled within 0.1%.

2.1 Photocathode RF gun and a linac

The 1.6 cell photocathode RF gun with a Cu cathode was developed for high repetition rate operation by BNL/KEK/SHI collaboration[4]. The gun has three cooling channels to remove the RF heating and control the temperature of the gun for high duty operation. The linac is a S-band alternating-periodic structure type with 11 accelerating cells and 10 coupling cells. Temperatures of cooling water for the gun and the linac are controlled within 0.1 degree, independently.

15MW RF power from a Klystron is divided into two. Each power is adjusted with a 4-port power variator with a circulator. A phase shifter adjusts the phase between the gun and the linac. The RF pulse width is 3μs at FWHM. The maximum repetition rate is 50Hz.

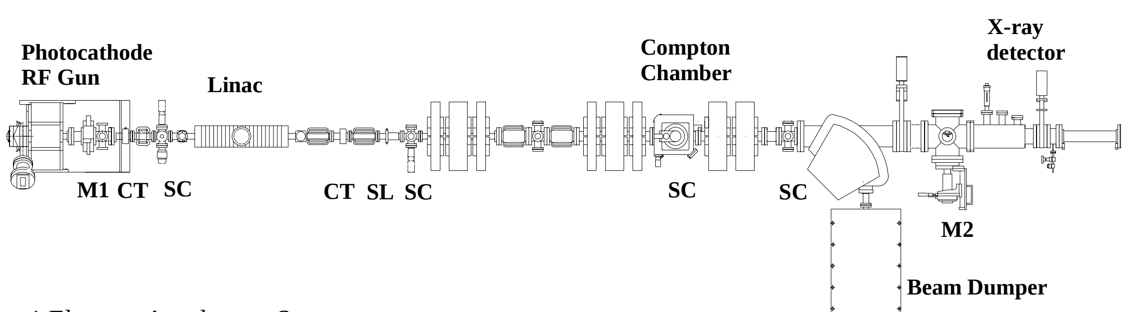

Fig. 1 Electron Accelerator System
M1,M2: Optical mirrors, CT: Current Transformer, SC: phosphor Screen, SL: Strip Line Monitor

2.2 Picosecond Laser for the Photocathode RF gun

The all solid LD-pumped Nd: YLF laser consists of a passive mode-locked oscillator with a semiconductor saturable absorber mirror (SESAM) and a regenerative amplifier. The frequency of the oscillator is 119 MHz being equal to 1/24 of the 2856 MHz S-band RF. A timing stabilizer measures the phase and the frequency offset between the laser pulses from the oscillator, 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. Timing jitter of the oscillator measured by a phase detector technique was within 0.5ps. The regenerative amplifier is operated with 1-100Hz repetition rate. The 1053nm fundamental with 2mJ pulse energy is quadrupled to 263nm UV radiation with 200μJ pulse energy by two non-linear crystals. The stability of the 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.

Alternative injection ways of the laser light are available. One is a normal injection. UV light from the laser is injected by a prism set at the downstream of the gun. The another is an oblique injection. UV light with p-polarization is injected at almost 70 degree. In both systems, laser profile on the cathode is controlled by an imaging lens and the position on the cathode was adjusted by a remote-control mirror.

Table 1 Specifications of the laser

Laser material	Nd:YLF
wavelength	263nm (4^{th} harmonics)
Pulse duration	12ps @1053nm
Pulse energy	200μJ/pulse@263nm
Repetition rate	1-100Hz
Energy stability	<1%@263nm
Timing jitter	<0.5ps@oscillator

2.3 Beam transport and Compton chamber

Electron bunches generated from the photocathode RF gun are accelerated through the gun and the linac up to 12MeV. Electron bunches are focused at an interaction point by using two triplet quadrupole magnets. After the interaction point, electron bunches are expanded easily and make a high background for X-ray detectors The doublet quadrupole magnet is set at the downstream of the interaction point to transport the whole beam to a beam dumper. Then, electron bunches are bent with a magnet with angle of 90 degree.

2.4 Diagnostic system

Phosphor screens with 0.1mm thickness, current transformers (CT) and a beam stripe line are set along the beam line as diagnostic elements of the electron beam. Fast response CTs with a by use of an amorphous core are manufactured by Pulse Electronic Engineering Co., Ltd. These are set at the downstream of the gun and the linac to monitor the electron bunch charge. The phosphor screen at the interaction point is used for adjusting the electron beam and the laser light for a Compton scattering experiment in space and temporal domain within ten picoseconds. Both of fast components from the phosphor screen and the laser light are lead to a streak camera with a several ps resolution. Then, the timing between the electrons and the laser light is adjusted with phase shifters and/or an optical delay line.

2.5 Synchronisation system and RF system

A block diagram of the synchronisation system for the operation of the X-ray system is shown in Fig.2. A RF signal generator supplies 2856 MHz radio frequency. This RF signal is divided into two. One drives the accelerators. The another is divided in frequency by 24 to 119MHz to drive the lasers for both of the photocathode RF gun and the X-ray generation. A synchroniser generates triggers synchronised between the power line (50Hz) and the laser drive RF signal (119MHz). These signals are used for a Pockels Cell of the laser, RF driver, and measuring systems, such as a streak camera. Two low power phase shifters are used for adjusting the timing among the two laser light and the RF phase of accelerator. And one high power RF phase shifter is installed in the wave-guide to adjust the phases between the gun and the linac. The output pulse of the RF power supply has 0.15% flatness and 0.17% stability within 2.1μs effective pulse width.

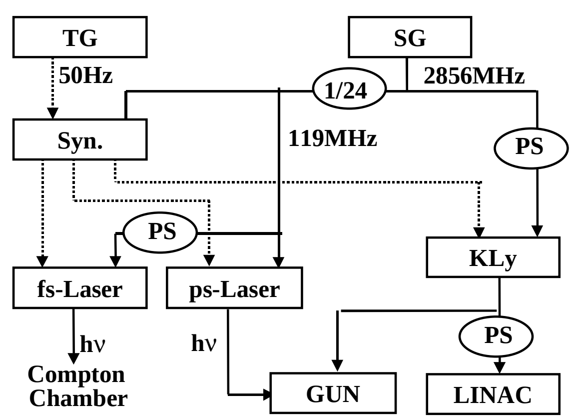

Fig.2 Block diagram of Synchronisation and RF system
TG: Trigger Generator, SG: RF Signal Generator,
Syn: Synchroniser; Kly: Klystron, PS: Phase Shifter

3 RESULT OF COMMISSIONING TEST

Commissioning tests of the electron accelerator system were performed. UV light of 200uJ was lead into the gun. Charge of emitted electron was obtained to be 1nC/pulse at maximum. Quantum efficiency was obtained to be $2.0x10^{-5}$. Electron energy after the gun was measured by using a dipole magnet and a screen. The charge and energy vs. the laser injection phase are shown in fig.3. In this case, laser light was sliced with an iris, then the laser energy was about 140uJ/pulse.

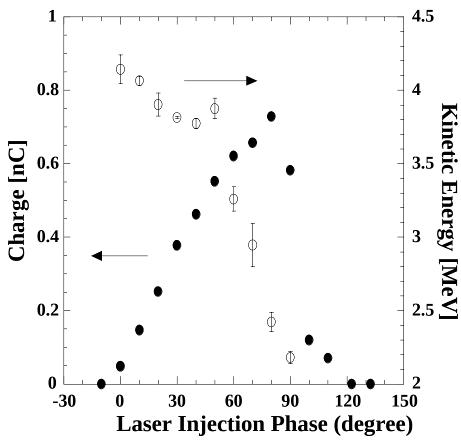

Fig.3 Charge and energy of electron bunches emitted from the gun vs. laser injection phase
solid circles: charge, circles: energy

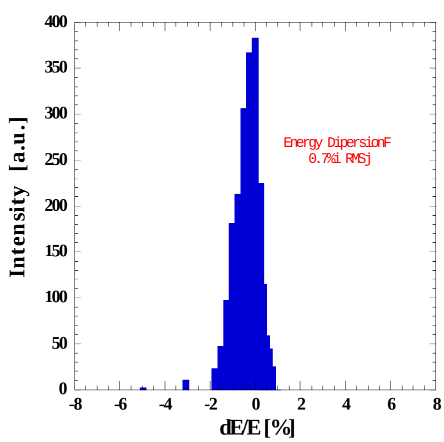

Fig.4 Energy distribution of electron bunches after the linac

The zero degree of the injection phase corresponds to the zero-field at the cathode. The charge at more than 80-degree was decreased suddenly. The current of a solenoidal magnet was fixed, so low energy electrons did not come out enough from the gun.

The electron bunches from the gun were accelerated up to 12MeV by the linac. When the laser injection phase was around 30 degree and the phase of the linac was at near the crest, the energy dispersion was minimum. Energy dispersion (dE/E) was 0.7% (rms.) as shown in Fig.3.

4 CONCLUSION

The electron accelerator system was installed and the commissioning test was performed. The detail characteristics of the electron bunch, such as the emittance, the bunch length and the stability in space and temporality will be studied. The femtosecond Ti:Sa laser with 100-fs pulse duration and 200mJ/pulse will be installed this fall to demonstrate the generation of femtosecond Compton X-ray pulse. In the near future, the electron energy and the laser power will be increased to generate higher energy and higher brightness X-ray.

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