A 40MEV ELECTRON SOURCE WITH A PHOTOCATHODE FOR X-RAY GENERATION THROUGH LASER-COMPTON SCATTERING

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Abstract

We have been developing a short pulse x-ray generation system based on Laser-Compton scattering. A stable electron source with 40MeV energy was developed to generate 30keV X-ray pulses in a head-on collision configuration. Electron energy of 38MeV with 0.2% bandwidth (FWHM) was measured by a bending magnet. Normalized emittance was measured to be 3.5 mm.mrad (rms).

INTRODUCTION

Ultra-short pulse x-ray sources are important tools for studying the dynamics of materials through their interactions with core electronic levels in atoms on fundamental time scales. X-ray generation using Laser-Compton scattering between relativistic electrons and short-pulse laser light is characterized by short pulses in the femtosecond region [1]. This X-ray source has not only short pulse in femtosecond region but also other advantages, such as good directional radiation, high brightness, quasi mono-chromaticity and wavelength tunability. This source also has other potential applications such as in protein crystallography, medical imaging for mammography using phase-contrast techniques, and industrial applications such as the non-destructive inspection of high-speed rotating materials.

We have been developing a short-pulse X-ray generation technology using Laser-Compton scattering. We achieved X-ray generation with a 90-degree collision configuration three years ago [2]. The maximum energy of the X-ray was 2.3keV, and the total number of photons was 10^4/pulse. Pulse duration was estimated to be 300fs (rms) from the beam parameters of the electron and laser pulses. These X-ray characteristics do not satisfy the requirements for many applications. We then attempted to modify the system to increase X-ray photon energy and the number of photons per pulse, and stabilize X-ray intensity [3]. Electron energy was increased from 14MeV to 38MeV (the maximum energy of X-rays is 15keV in the 90-degree configuration and 30keV in the head-on collision configuration). The system was also modified to be useful for some X-ray applications.

Here we report the modified electron system and the characteristics of electron pulses, such as energy, emittance, and stability.

ELECTRON SOURCE SYSTEM

Figure 1 systematically illustrates the electron source system. The system consists of an acceleration section, including a gun and linacs; a bending section for reducing gamma-rays from the acceleration section at an application section for users; and an interaction section between laser and electron pulses, including focus magnets and a 90-degree bending magnet for electron beam dumping.

We used a photocathode RF gun (BNL type: GUN-VI) with Cu cathode as an electron source. The driving laser was a pico-second Nd:YLF laser, pumped by laser diodes. The oscillator frequency is 79.3MHz, which is 1/36 of 2856MHz for the electron accelerator. The timing jitter between the oscillator and the reference 79.3MHz RF signal was reduced within 1ps by a standard phase-locked loop (PLL) feedback control. The fourth harmonic frequency-multiplied by two BBO crystals was expanded by lenses, and filtered by a 2-mm-diameter iris to produce an almost flat transverse profile. The laser energy after the iris was nearly a half of the original laser energy. The transverse laser beam profile at the iris was imaged onto the cathode surface by an imaging lens. We set a prism close to the electron beam line, 60cm from the cathode. The laser beam reflected at the prism and was directed almost a normal onto the cathode surface. We accelerated the electron pulses from the gun to 38MeV through two 1.5m-long standing wave linacs.

RF pulses supplied from the klystron had a peak-power of 20MW and a pulse width of 4-μs. One fourth of the RF power was supplied to the gun, and the residual power was divided between two linacs. High-power phase shifters were located before the linacs, and the RF phases of the two linacs were changed individually. The RF phase usually fluctuates slowly due to temperature and other circumstance changes. An RF phase feedback circuit (Nihon Koshuha Co., Ltd.) was used to compensate for the phase change and provide long-term stabilization of the RF phase. The RF phase was extracted from a directional coupler at the gun, compared with the RF phase from the synthesizer by a phase detector, and adjusted to maintain the phase difference.

The system incorporated an achromatic bending system consisting two 45-degree bending magnets and four quadrupole magnets. Gamma-rays coming directly from the acceleration cavity were reduced at the application section. Additionally, most field emission electrons with a wide energy range were dumped at this section, which caused less background for x-ray application experiments. The Q-magnets were divided into two groups, the first and fourth Q-magnets, and the second and third Q-magnets. Magnets in the same group were set to the same strength. The stability of electric power supplies for the 45-degree bending magnets is important to the pointing stability of the electron beams. The current stability of the power supplies is less than $2x10^{-5}$, by a feedback control.

We will control the temperature of the current sensor, to stabilize the power supplies to less than 10^{-5}.

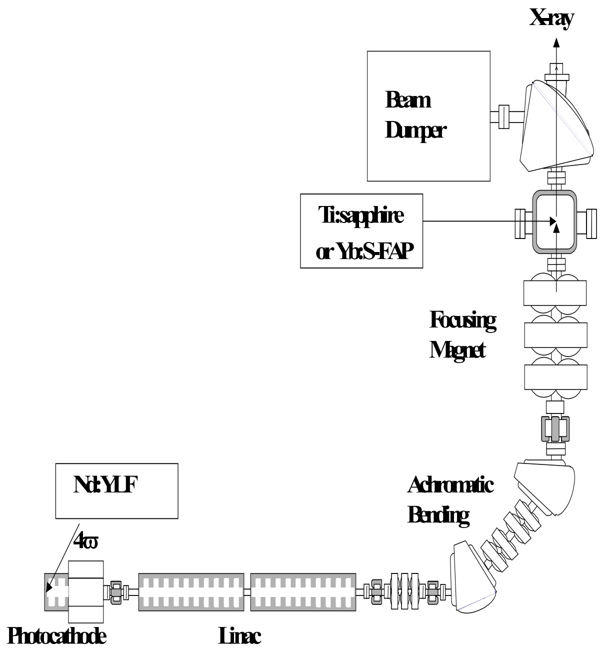

Figure 1 Schematic drawing of the electron source for Laser-Compton scattering

EXPERIMENTAL RESULTS

Energy

Electron energy and a bandwidth are strongly dependent on the phases of the gun and linacs. Laser injection phase in the gun was fixed at 25 to 30 degrees, where we obtained the best emittance. The RF phase of first linacs was adjusted to obtain the minimum energy bandwidth. The RF phase of the second linacs was set at the crest. After achromatic bending, the position of the electron beam was adjusted in the center of a triplet focus magnet. The measurement of electron energy used a 90-degree bending magnet and a slit. As the field strength of the bending magnet was changed, a Faraday cup measured the electron pulse charge through the slit. The energy of the electron beam was 37.8MeV with 0.2% bandwidth (FWHM), as depicted in Fig. 2.

Emittance

Emittance was measured at an interaction point by the normal Q-scan method. We used a 30-μm thick phosphor screen. The minimum measured beam radius was limited by the screen thickness. We adjusted the beam radius using the other Q-magnets before using the Q-magnet in the Q-scan method. Emittance depended on the variation of Q-magnets strength between the 45-degree magnets in the achromatic section. The field strength of Q-magnets

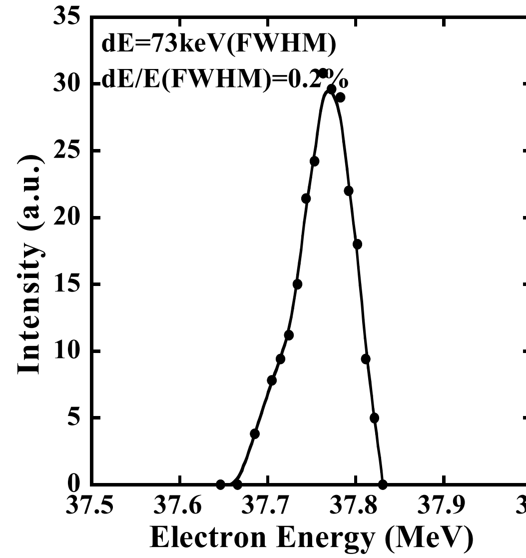

Figure 2 Energy distribution of the electron bunch. Circles are experimental data. A solid line is smoothing the data.

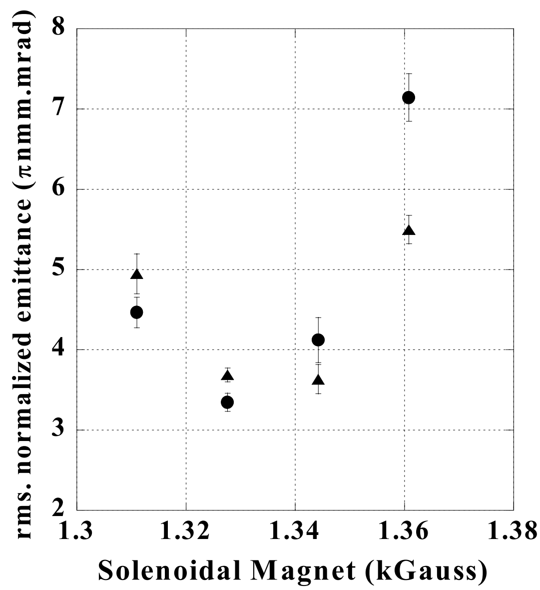

Figure 3 Normalized emittance (rms.) dependence on field of the solenoid magnet.
Circles and triangles are data in horizontal and vertical direction, respectively. Error bars shows fitting errors.

was adjusted to obtain the minimum emittance in both the horizontal and vertical directions. The dependence of the normalized emittance (rms.) on soleμm noid magnet field strength in the horizontal and vertical directions is illustrated in Fig. 3. In this measurement, the laser injection phase in the gun was 25 degrees, and the electron charge was 0.8nC/pulse.

Stability

We installed a phase feedback circuit and stable power supplies for the 45-degree bending magnets to stabilize the electron beams for expected periods of time. We focused the electron beams at an interaction point to measure the pointing stability and the stability of the beam radius and obtained 1,200 beam profiles over a 30-minute span for the stability analysis. The average beam radius was 82 μm horizontally and 61 μm (rms) vertically. The pointing jitter of the beam center were 5.3 μm horizontally and 1.4 μm (rms.) vertically (Fig. 4). The vertical pointing jitter was due to system instability, such as vibration of the apparatus, laser pointing instability, and misalignment of the magnets. The horizontal pointing jitter includes the above system instability and the current jitter of the power supplies for the bending magnets. However, these stabilities are sufficiently small relative to our targets, less than 1/10 of beam radius [4].

We also analyzed the beam radius jitter. The radius jitters of the radius were 5.3 μm horizontally and 1.4 μm rms vertically. This results from the pulse charge jitter (space charge), phase jitter (energy jitter), etc. Our target is less than 1% of the beam radius [4]. We have to study the main reason of the beam radius jitter and stabilize the system better.

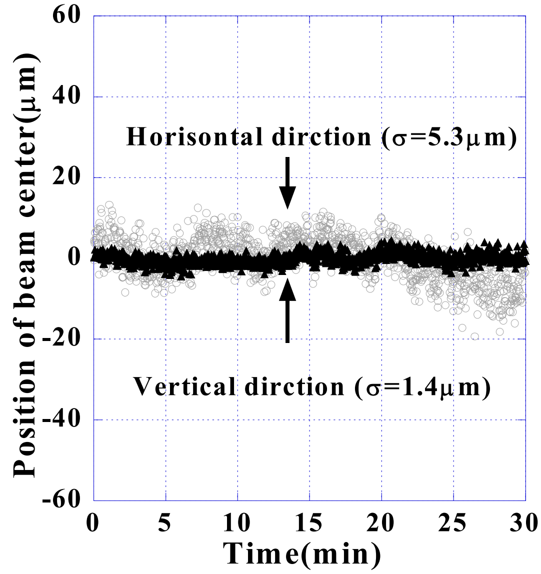

Figure 4 Fluctuation of the beam center.
Circles and triangles show the center of the electron beam in the horizontal and vertical direction, respectively.

SUMMARY

We developed an electron system and have started x-ray generation experiments. We will establish the whole system including laser system, and diagnose the electron and laser systems based on the characteristics of the generated x-rays. We will also demonstrate experiments using x-ray pulses, such as imaging.

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