BEAM GENERATION AND ACCELERATION EXPERIMENTS OF X-BAND LINAC AND MONOCHROMATIC KEV X-RAY SORCE OF THE UNIVERSITY OF TOKYO*

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Abstract

In the Nuclear Professional School, the University of Tokyo (UTNS), we are constructing an X-band linear accelerator that consists of an X-band thermionic cathode RF gun and X-band accelerating structure. This system is considered for a compact inverse Compton scattering monochromatic X-ray source for the medical application. The injector of this system consists of the 3.5-cell coaxial RF feed coupler type X-band thermionic cathode RF gun and an alpha-magnet. The X-band accelerating structure is round detuned structure (RDS) type that developed for the future linear collider are fully adopted. So far, we have constructed the whole RF system and beam line for the X-band linac and achieved 2 MeV electron beam generation from the X-band thermionic cathode RF gun. In addition, we achieved 40 MW RF feeding to the accelerating structure. The laser system for the X-ray generation via Compton scattering was also constructed and evaluated its properties. In this paper, we will present the details of our system and progress of beam acceleration experiment and the performance of the laser system for the Compton scattering experiment.

INTRODUCTION

X-rays of 10-40 keV are great use in medical science, biology, and material science. Example techniques that are use such monochromatic X-rays are dual-energy X-ray CT [1] and subtraction imaging using a contrast agent and dual energy X-rays. These techniques may be realized by using two monochromatic X-ray beams.

Intense high energy (10-40 keV) X-rays are generated by the third-generation light source such as SPring-8, APS, and ESRF. However, most synchrotron radiation sources are too large to be widely used for monochromatic X-rays. One solution to realize a remarkable compactness is laser-electron collision (Compton scattering or Thomson scattering). Recently, many facilities are developing a Compton scattering X-ray source that consists of an electron linac and laser system [2-5]. However, most of them use the scattering between an ultra-short single electron bunch and an ultra-short single laser pulse to obtain short pulse X-ray beam. Therefore, they suffer a lack of X-ray intensity up to 10^8 photons/s and the fluctuation of the X-ray intensity due to the timing jitter between the electron bunch and the laser pulse. In order to overcome this weak point of Compton scattering X-ray source, one solution would be multiple scattering between multi-bunch electron beam and long-pulse laser beam. In the University of Tokyo, we are developing a more compact, high intensity, and high stable Compton scattering X-ray source. Our system consists of a 30 MeV X-band (11.424 GHz) multi-bunch electron linac and a Q-switch Nd: YAG laser (1.4 J/10 ns, 532 nm, second harmonic). In this paper, we describe the details of the high power and beam generation and acceleration experiment of the X-band linac with thermionic cathode RF gun and the details of the experimental setup for Compton scattering X-ray generation that are under construction.

X-BAND LINAC FOR INVERCE COMPTON SCATTERING X-RAY SOURCE AT THE UNIVERSITY OF TOKYO

Figure 1 shows schematic of the compact X-ray source at the University of Tokyo. Multi-bunch electron beam generated by a 3.5-cell X-band thermionic cathode RF gun, and is collimated and compressed by an alpha magnet, and accelerated by an X-band traveling type accelerating structure. The electron beam is bent by achromatic bends and focused at the collision point. The thermionic cathode RF gun can generate a high-current (2 μA) multi-bunch (10^4 bunches in 1 μs) electron beam. So far, we have achieved 2 MeV electron beam generation from the RF gun [6].

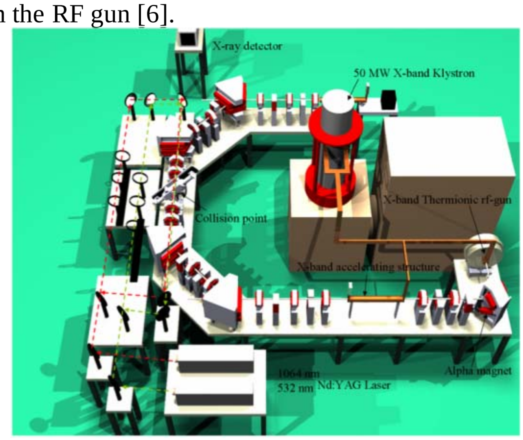

Figure 1: Schematic illustration of the compact Compton scattering X-ray source based on the X-band thermionic

* This work is performed under the national project of Development of Advanced Compact Accelerators in Japan and is partially supported by the Research Program on Development Innovative Technology (#0494) of the Japan Science and Technology Agency and in part supported by Health and Labour Sciences Research Grants.
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cathode RF gun, X-band accelerating structure, and a Q-switch Nd: YAG laser at the University of Tokyo.

HIGH POWER TEST AND BEAM ACCELERATION EXPERIMENT OF X-BAND LINAC

The whole system of the RF system for the X-band thermionic RF electron injector and the X-band traveling wave accelerating structure is illustrated in Fig. 2. Low-level RF feed the RF about 300 W to the klystron. The variable attenuator that located at just before the klystron input port can control this input power. In order to reduce a load of the RF windows, there are two output ports at the klystron. Photo-multiplier tubes (PMT) are set to observe the light of breakdown on the RF windows and dummy loads. RF detectors at directional couplers observe the waveforms of the RF. These signals are guided to a fast interlock system. The fast interlock system stops the RF within 400 ns. Reflection signal from the dummy load is also used for the interlock. The RF pulses output from the klystron are combined by 3 dB hybrid and feed to beam line floor. The RF pulse is divided by 7 dB hybrid. In nominally, 40 MW and 6 MW with the pulse width of 1 μs are fed to the accelerating structure and the thermionic RF injector. In order to reduce the reflection from the RF gun cavity, we set 2.2 dB hybrid just after the 7 dB hybrid. So far, we have carried out the RF conditioning and achieved total output power about 40 MW and pulse width about 150 ns under 10 Hz operations. Figure 3 shows an example of history of RF processing. Figure 4 and 5 show the typical waveforms input to the accelerating structure and thermionic RF injector. The reason why the reflection waveform from the gun cavity seemed that the RF power is not filled in the cavity is due to the beam loading by emitted electron from the thermionic cathode.

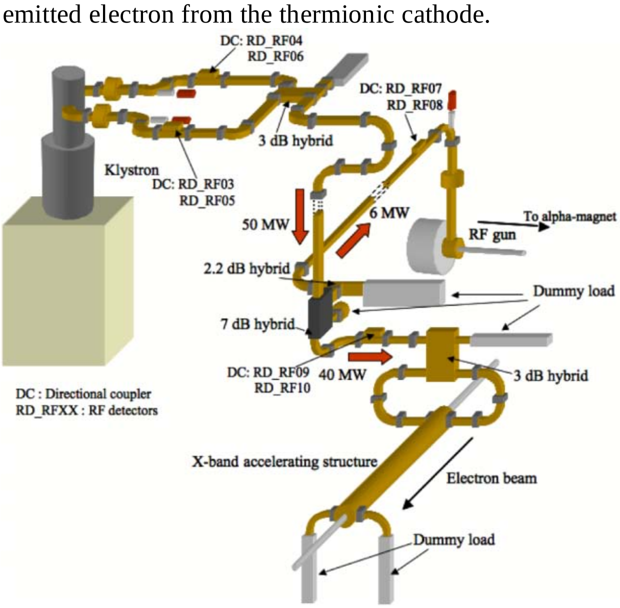

Figure 2: Schematic layout of the RF system for X-band thermionic RF injector and traveling wave accelerating structure.

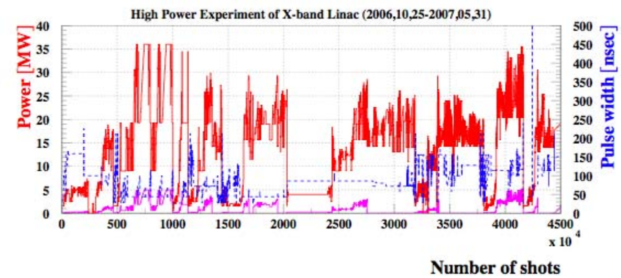

Figure 3: Example of the RF processing history. Red line shows RF power fed to accelerating structure, pink one is to the RF injector, and dotted blue line indicates the pulse width of the RF pulse.

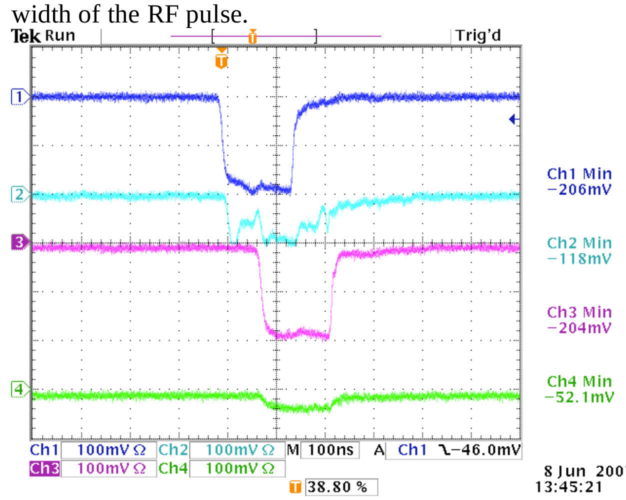

Figure 4: Typical waveform of RF pulse. (Ch.1: output from the klystron, Ch. 2 : reflection to klystron, Ch. 3: input to accelerating structure and Ch.4 :reflection from accelerating structure.

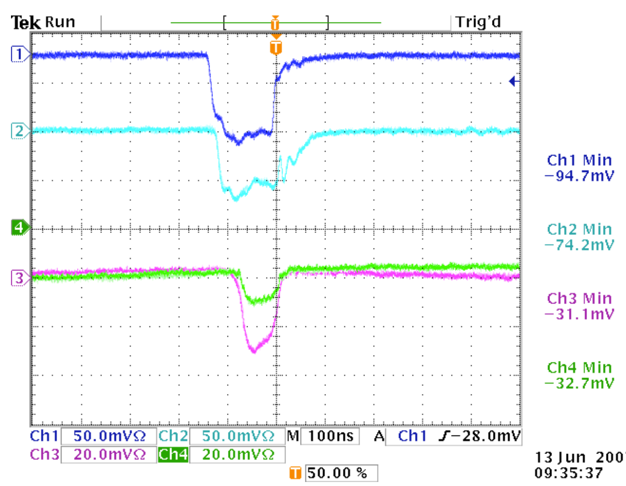

Figure 5: Typical waveform of RF pulse. (Ch.1: input to thermionic RF injector, Ch. 2: reflection from the injector, Ch. 3: beam current just after the alpha magnet and Ch. 4: beam current after the alpha-magnet.)

The beam optics for Compton scattering X-ray source were designed by using SAD (Strategic Accelerator Design) program [2,3]. After the alpha-magnet, the multi-bunch electron beam is passing trough quadruple doublet and injects into the 0.5m accelerating structure. Figure 6 shows the beam profile at just after the accelerating structure. The beam energy is estimated about ?? MeV by using bending magnet.

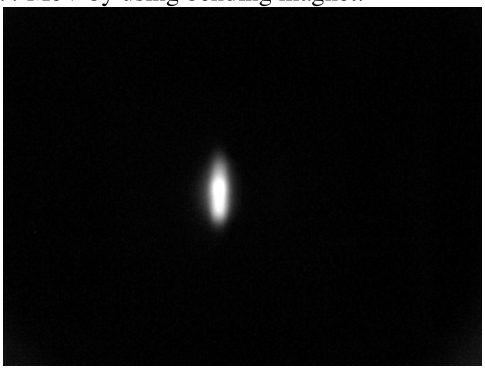

Figure 6: Beam profile at just after accelerating structure measured by luminescence screen.

EXPERIMENTAL SETUP FOR X-RAY GENERATION VIA COMPTON SCATTERING

For the next step, we are constructing a beam line of the X-band accelerating structure and Nd: YAG laser system for the X-ray generation via Compton scattering. Figure 7 shows the experimental setup for the Compton scattering. The X-band 0.5 m travelling-wave type accelerating structure accelerates the multi-bunch electron beam up to 30 MeV, and the beam is bent by achromatic bends and focused at the collision point. Since the laser pulse width, 10 ns (FWHM) is much shorter than the macro-pulse width of the electron beam (1 μs), we adopt a laser pulse circulation system [9,10]. Recently, we have carried out the measurement of the laser properties. The M^2 parameter is measured as 1.6 and 1.8 for horizontal and vertical, respectively. Figure 8 shows the stability of the laser pulse transverse beam size. The fluctuation of the beam size is with in 10 %. We will demonstrate the X-ray generation experiment via Compton scattering this July.

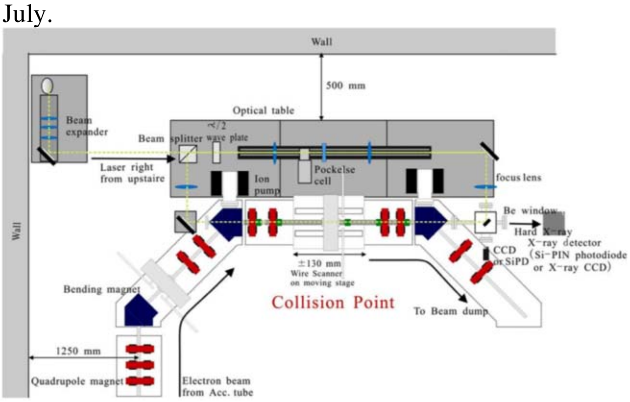

Figure 7: Experimental setup for X-ray generation via inverse Compton scattering at the University of Tokyo.

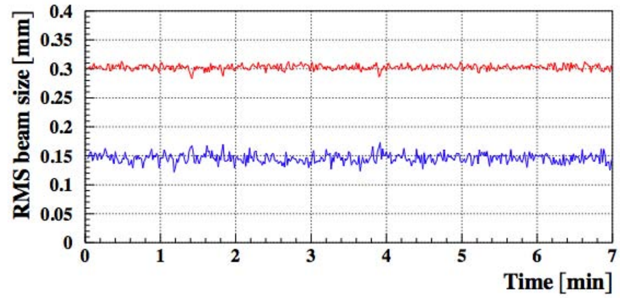

Figure 8: Stability of laser spot size at the collision point (top: horizontal, below: vertical).

SUMMARY

We are developing the compact, highly-intensity-, and highly-stable-Compton scattering X-ray source based on X-band multi-bunch electron linac and reliable Nd: YAG laser. So far, we have achieved the beam generation from the X-band thermionic cathode RF gun and carried out the beam acceleration experiment. The maximum beam energy is estimated about ?? MeV. This experimental high energy beam generation and acceleration from by the X-band thermionic cathode RF gun is the first achievement in the world. For the next stage, preparations for the beam acceleration and laser system for Compton scattering are underway. We will perform the experiments on the beam acceleration and the Compton scattering X-ray generation this October.

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