X-BAND THERMIONIC CATHODE RF GUN AT UTNL

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Abstract

A compact Compton scattering hard X-ray source is being developed at Nuclear Engineering Research School (old Nuclear Engineering Research Laboratory). This is considered to be used in the medical scene in the future. This system consists of 50 MeV X-band electron linac and YAG laser to produce 40 keV (fundamental) and 80 keV (the second harmonic). The linac has a thermionic cathode X-band RF gun and an alpha magnet as an injector. Traveling wave tube accelerate the beam up to 50 MeV.

The simulation shows the beam from the gun must be cut off its lower energy part. Alpha magnet with inner slits act as the role, and at the slit position 122 mm energy spread requirement was satisfied, but the charge became small. We must search better operation parameters.

A test beam line to demonstrate production of Compton scattering hard X-ray is under construction. Conditioning of a thermionic cathode X-band RF gun is being proceeded. Feeding with 1.5 MW 100ns was achieved (6 MW 400ns is required for test).

INTRODUCTION

Monochromatic hard X-rays enables advanced diagnostics such as dual X-ray CT[1] and IVCAG[2]. However the spectra of conventional hard X-ray sources are broad since they are bremsstrahlung radiation produced by electrons hitting against targets. A monochrometer can select narrow spectrum but the intensity decreases considerably. Only radiation at storage rings is possible to obtain sufficient intensity through a monochrometer. Its property is very good but the source has difficulty in its huge size for widely use. Compton scattering is one of the solutions to obtain narrow spectrum by putting a hole slit. Since it dose not require a monochrometer, the efficiency to obtain monochromatic X-ray becomes higher.

A compact Compton scattering hard X-ray source for medical use is developing at Nuclear Engineering Research Laboratory (UTNL) [3, 4]. It consists of 50 MeV electron linac and YAG lasers. In the first phase of this study, we will show the validity of our design by the production of Compton scattering hard X-ray. The test beam line is shown in Fig. 1 and the design parameters are in Table 1. The energy spread are required to be less than 1% for focusing at collision point. RF gun is introduced for its low emittance beam production. A thermionic cathode is expected pulse-to-pulse stable operation, although there are problems about backbomberedment. A thermionic carhode RF gun produces multibunch beam (in our case, 10^4 bunches in a 1μs-long RF pulse).

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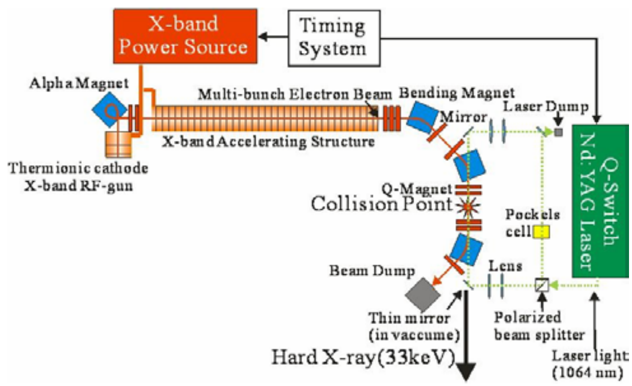

Figure 1: Beam line for a test of Compton scattering.

Table 1: Design parameters

Beam energy	35 MeV
Charge of a bunch	20 pC
Bunches in a pulse	10^4
Normalized emittance	10 πmm.mrad

THERMIONIC CATHODE RF GUN

The injector of this system consists of a thermionic cathode X-band RF gun and an α magnet. An α magnet is used to eliminate low energy particles by its inner slits. Bunch compression is also expected there. Since the energy spread after main acceleration is required to be less than 1%, beams from the injector must satisfy the following equation,

$$\delta = \frac{\Delta E_{inj} + E_{acc} \Delta \phi_{inj}^2}{E} < 0.01$$

where ΔE_{inj} is the energy spread at injector, $\Delta\phi_{inj}$ the bunch length in radians, and E_{acc} the energy gain in the main accelerating structure.

3.5-cell Cavity

Our gun cavity has 3.5 cells (Fig. 3) and is operated at π mode. Coaxial coupler [5] is introduced for axial symmetry of the field in the gun and to place inside solenoid coil. The cathode is dispenser type and the material is tungsten. It will be operated at the current density, 20 A/cm^2.

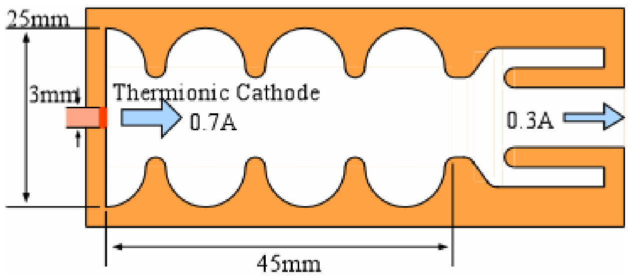

Figure 2: RF gun cavity.

Output of the Gun

The dynamics of the particles in the gun was simulated by PARMELA [6]. The total charge is 41 pC. The bunch length is 4.4 ps and the energy spread 0.16 MeV (those are rms over 2.25 MeV particles) (Fig. 3, 4). Since δ becomes 0.10, lower particles should be eliminated. When the particles less than 2.8 MeV is cut off, the bunch satisfy the energy spread condition (Fig. 5).

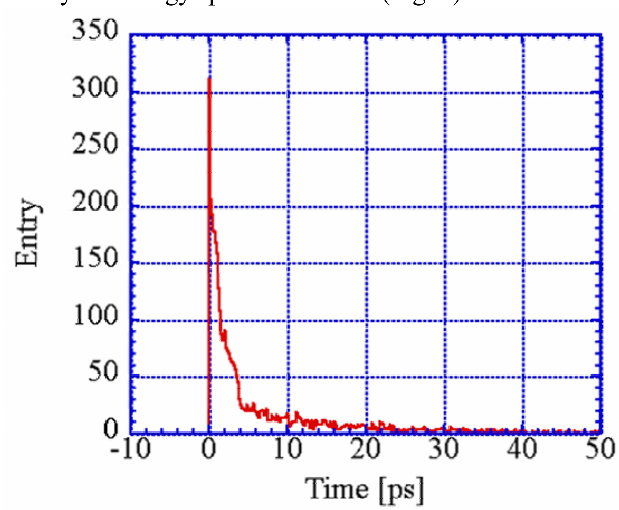

Figure 3: Bunch form (left) before alpha magnet.

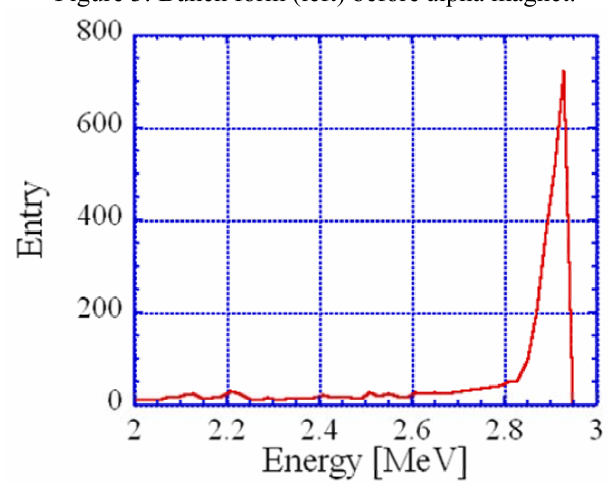

Figure 4: Energy spectrum (right) before alpha magnet.

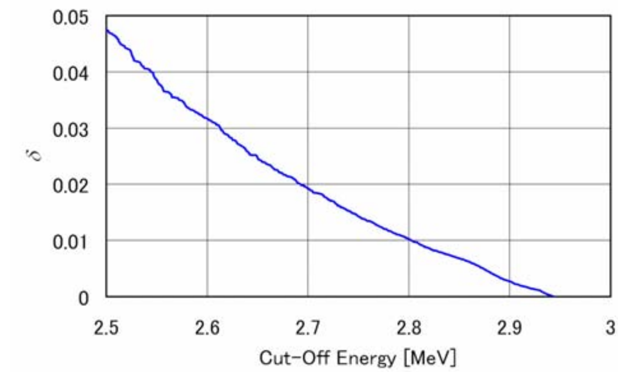

Figure 5: Relation between cut-off energy and estimated energy spread after main acceleration

Slit Position in α Magnet

The motion in the α magnet was calculated next. There is a slit to cut low energy particles in the α magnet. Moving this slit, the cut-off energy can be controlled (Fig.6). The bunch parameters after that are listed in Table 2. When the slit position is 121 mm, the condition is not satisfied. Although 122 mm satisfies it, the charge becomes small. Cut-off energy is higher than estimated in the previous section. This is because over bunching occur in α magnet and bunch length becomes longer. To obtain the best compression and high charge, the field gradient in the α magnet must be higher. However it is difficult to increase the field. Then the energy should be decreased.

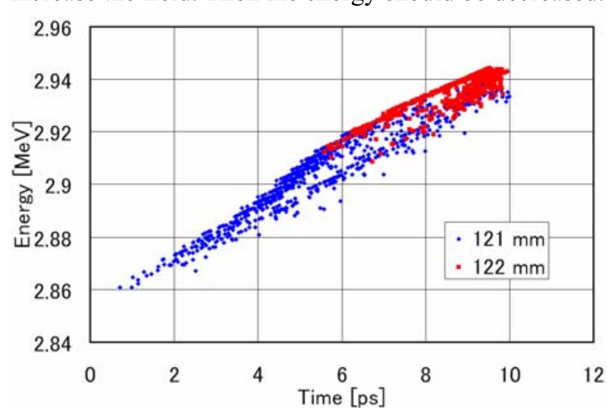

Figure 6: Particle distribution in time-energy space. Blue dots are for the slit position 121 mm and red for 122 mm.

Table 2: Bunch parameters after the α magnet

Position of slit	121 mm	122 mm
Charge	20.2 pC	7.5 pC
Energy	2.92±0.02 MeV	2.94±0.01 MeV
Cut-off energy	2.86 MeV	2.91 MeV
Normalized emittance	15.1, 6.3 πmm.mrad	10.2, 4.1 πmm.mrad
Bunch length	2.2 ps	1.0 ps
δ	0.024	0.005

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PREPARATION FOR THE GUN TEST

The beam line for the test of the thermionic cathode X-band RF gun was constructed in this March. For the test the gun cavity must be processed by RF conditioning. After the conditioning beam experiment will be carried on.

Frequency Tuning

To check the tune of the cavity, we measured the return reflection from the gun. The pulse shapes of RF propagating forward and backward are shown in Fig. 7. The pulse propagating forward has spike in the head. Since there are no circulators which could sustain high power at X-band frequency, the reflected pulse returns back into klystron directly and come back to the gun again affecting the forward pulse.

To find a lowest reflection, frequency survey is performed. The minimum of the return loss are observed at 11.42450 GHz (Fig. 8). We changed the operation frequency 11.42400 to 11.42450 GHz.

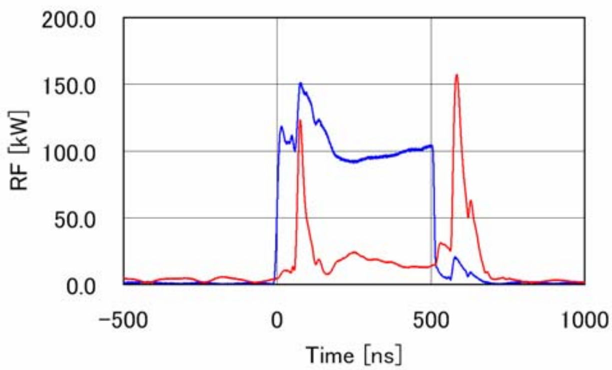

Figure 7: RF pulse shape into (blue) and reflected back from the gun cavity.

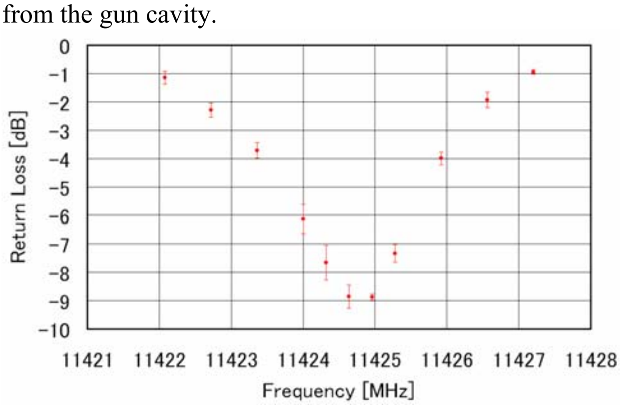

Figure 8: Return loss at the gun cavity.

RF Gun Conditioning

RF gun conditioning started in this April. The RF power 1.5 MW and the pulse length 100 ns achieved on May 13 while 6 MW and 400 ns is required for the test.

SUMMARY

We are developing a compact hard X-ray source. It requires the energy spread less than 1 %. Energy selection must be introduced and an alpha magnet with inner slits serves as that role. When the slit position came to 122mm, the condition was satisfied, however the charge became small. We are looking for better conditions.

A thermionic cathode X-band RF gun is being prepared for test. RF tuning was performed and 11.42450 GHz was chosen since the lowest reflection. RF gun conditioning began in this April. The RF status of the conditioning is now 1.5 MW 100ns while the goal is 6 MW 400ns.

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