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DESIGN STUDY ON LINAC-BASED LASER-COMPTON SCATTERING X-RAY SOURCE*

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Abstract

We have been developing a laser-Compton scattering X-ray source using multi-bunch linac and optical enhancement cavity. This combination have a possibility to realize a high brightness compact X-ray source. A key issue of the system is around interaction point. Compatibility of electron focusing, optical cavity and X-ray path is difficult in the current setup. Thus we propose to use rf transverse deflecting cavity for crab crossing of laser and electron. In this conference, design study of the whole laser-Compton X-ray source consist of electron linac and optical enhancement cavity will be reported. The system configuration, resulting flux and brightness, and its applications will be discussed.

INTRODUCTION

The high brightness X-rays are widely used in the various fields such as material science, biological science, medical diagnostic and so on. The compact X-ray sources would expand further the use of high brightness X-rays. The laser-Compton scattering (LCS) has a possibility to build a compact and high brightness X-ray source. In the view of relativistic electron undulation, a laser, which wavelength of 1μm, wiggle the electrons. The undulation period is much shorter than that of magnetic undulators of ~several cm. Therefore, the system requires low energy electrons to achieve the hard X-rays.

We have been studying a LCS X-ray source using multi-bunch electron linac and laser enhancement optical cavity[1]. The multi-bunch electron linac is based on photocathode rf gun and S-band accelerating structure and produces thousand bunches in macro-pulse with 2.8 ns bunch space. On the other hand, the laser pulses in the optical enhancement cavity exceeds more than 1 MW peak power, which correspond to the pulse energy of about 3 mJ/pulse. This successful results were based on burst storage technique[2]. Currently we have achieved to produce 1.4×10^8 photons/sec X-rays and performed an X-ray imaging. In this paper, we will present the recent progress of our LCS X-ray source, design studies of further development of linac based LCS X-ray source and future prospective.

LUCX LCS X-RAY SOURCE

We have been developing a compact LCS X-ray source at KEK named LUCX (Laser Undulator Compact X-ray source). The drawing of our LUCX facility is shown in Figure 1.

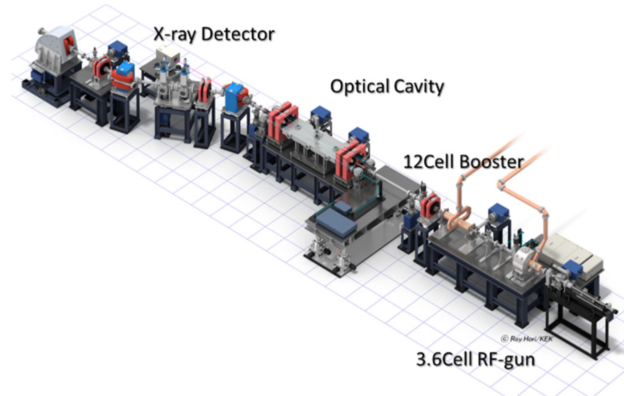

Figure 1: Schematic drawing of LUCX facility.

LUCX facility consists of multi-bunch electron linac and optical enhancement cavity. The electron beam is produced by photocathode rf electron gun and accelerated by the S-band standing wave accelerator up to 24 MeV. 1000 electron bunches are produced in one macro pulse with 2.8 ns bunch separation. The macro pulse repetition is currently 12.5 Hz. The electron beam is focused by the quadrupole magnets at the center of optical enhancement cavity. The optical enhancement cavity is formed by the 4 mirrors in a bow-tie shape. The pulse spacing of the laser pulse is also 2.8 ns. The input laser is burst amplified at the same time of electron macro pulse and the stored power in the cavity is increased (burst storage). The stored power exceeds more than 1 MW at the peak i.e. about 3 mJ pulse energy. Thus, more than 3 J of laser energy is interacted with the electron bunches. The other parameters are listed in Table 1.

Table 1: Parameters of Electron Beam and Laser Pulse in the Optical Enhancement Cavity

	Electron Beam	Laser Pulse
Energy	~24 MeV	1.17 eV(1064 nm)
Intensity	600 pC	2.8 mJ (1MW)
Transverse Size	80/60 μm	60/25 μm
Duration	15 ps (fwhm)	7 ps (fwhm)
N of bunch	1000	
Pulse space	2.8 ns	2.8ns
Repetition	12.5 Hz (rf)	12.5 Hz (burst)

The electron and laser are interacted at an angle of 7.5 deg. The resulting X-ray energy is 10 keV. We performed an X-ray flux measurement and X-ray imaging. The results are shown in Figure 2 and Figure 3 respectively.

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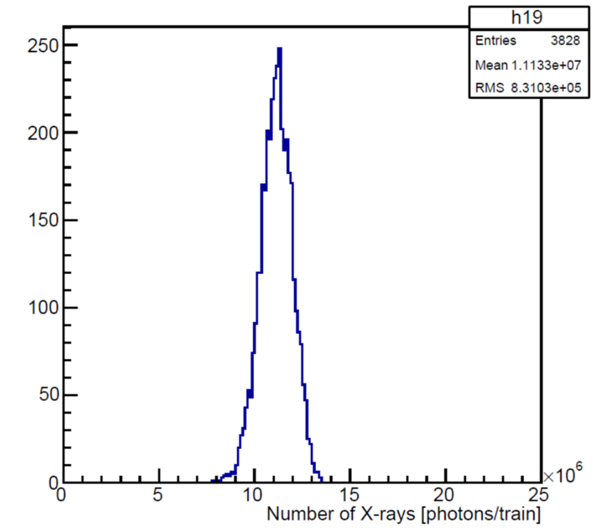

Figure 2: Histogram of LCS X-ray flux measurement. Flux are measured by each macro pulses.

The resulting X-ray flux was 1.1×10^7 photons/train and 1.4×10^8 photons/sec in 12.5 Hz repetition rate. The flux jitter was 7.4 % in rms, which caused by the laser and electron intensity jitter and position jitter. The flux was

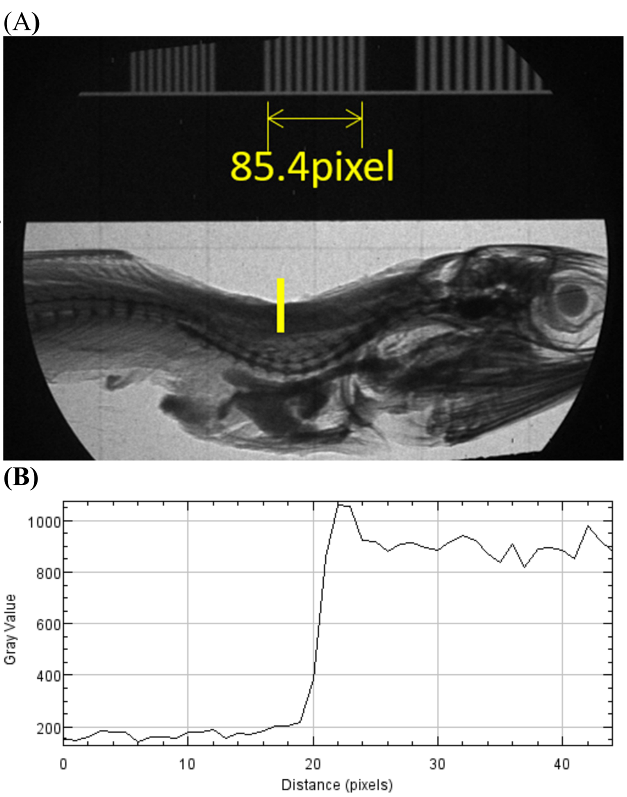

Figure 3: The result of LCS X-ray imaging of dried small fish. (A) Image of dried small fish with scale. (B) Line profile on indicated line in (A), the edge of the fish.

enough for the X-ray imaging, so we took the image of dried small fish. As shown in Figure 3, the image was clear and good spatial resolution. The important feature of this image is described in Figure 3 (B). This line profile is on the yellow line indicated in Figure 3 (A), which is the edge of dried fish. The edge was enhanced by the refraction of the X-ray, which indicated that the LCS X-ray source has small source size i.e. high brightness.

DESIGN STUDY OF LINAC BASED LCS X-RAY SOURCE

We started to design the compact X-ray source. The first target of the design is linac based, up to 15 keV X-ray energy and more than 10^{11}photon/sec/10%bw. The bandwidth of the X-ray looks large but one advantage of the LCS X-ray is the large area imaging due to the low electron energy thus we chose this bandwidth. The design was based on LUCX facility to upgrade. The schematic drawing of our concept is illustrated in Figure 4. Also the parameters of electron and laser are listed in Table 2

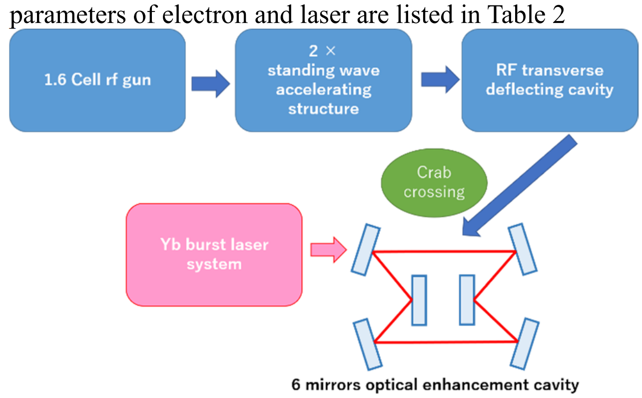

Figure 4: Schematic illustration of the upgraded LUCX facility.

The key points of the design are using crab crossing[3] for the collision, further development of the optical enhancement cavity and increasing the repetition rate.

Table 2: Design Parameters of Electron Beam and Laser Pulse in the Optical Enhancement Cavity

	Electron Beam	Laser Pulse
Energy	~30 MeV	1.2 eV(1030 nm)
Intensity	600 pC	300 mJ
Transverse Size	80/60 μm	20/20 μm
Duration	15 ps (fwhm)	1 ps (fwhm)
N of bunch	1000	
Pulse space	2.8 ns	2.8ns
Repetition	1 kHz (rf)	1 kHz (burst)

When we decided to use the optical enhancement cavity, it cannot be avoided to employ the certain crossing angle and/or X-ray loss in the cavity mirror. Moreover, the optical cavity design is strongly restricted by the crossing angle. In order to overcome this issue, we will apply the crab crossing in the LCS. The proof of principle experiment is planned in Ref. [4]. The transverse deflecting cavity makes the electron bunch tilt and it achieves quasi head on collisions. The detail of the crab crossing is described in Ref. [4], the case that only the electron bunch is tilted, it is important to use short pulse laser to maximize

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the luminosity of LCS. Thus, we will develop the optical enhancement cavity with shorter pulse laser.

The issue in the optical enhancement cavity is the damage on the cavity mirror surface by the stored laser. The laser power has already exceeded 1 MW, so the cavity mode in the cavity have to be expanded. In Figure 5, problems of 4 mirrors cavity and newly designed 6 mirrors cavity is illustrated.

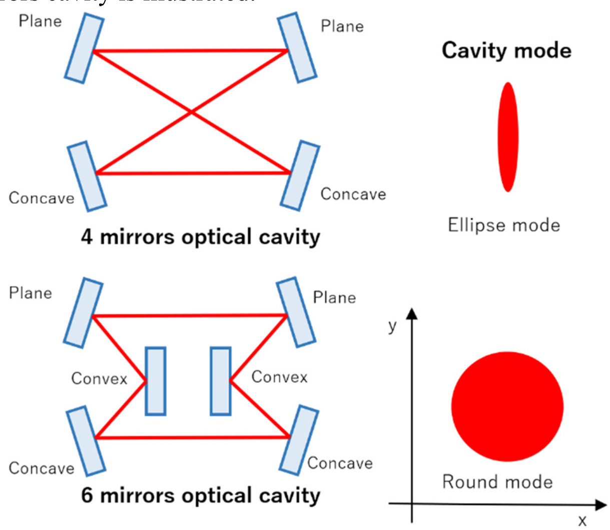

Figure 5: Comparison of 4 mirrors optical cavity and 6 mirrors optical cavity. The cavity forms are on the left and its cavity modes are on the right.

In case of 4 mirrors cavity, reflection angle of the concave mirror produces astigmatism between the sagittal and tangential plane. It causes the asymmetry mode of the light in the optical cavity. If we would like to expand the laser profile on the cavity mirror, the length between concave mirrors should be adjusted. However, the astigmatism prevents to expand both horizontal and vertical profile. The 6 mirrors cavity can cancel the effect of astigmatism. Combination of the concave mirror and convex mirror can produce round mode with large profile in the cavity as illustrated in Figure 5. Designed 6 mirrors cavity and its mode are shown in Figure 6. It can be found that the almost round and large profile is produced in the cavity. We will perform the first test of the 6 mirrors cavity in near future.

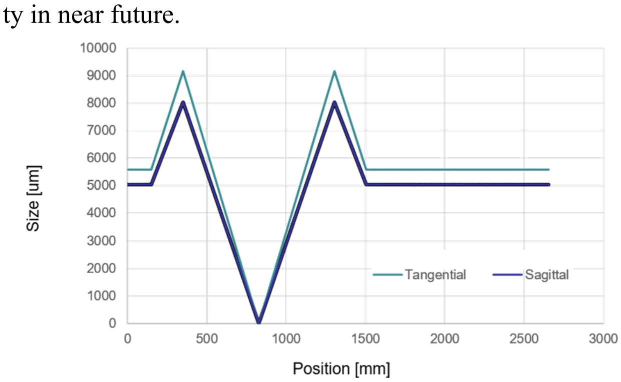

Figure 6: Calculated cavity mode profile in the 6 mirrors optical cavity using 2 plane mirrors, 2 convex mirrors and 2 concave mirrors.

Concerning about the repetition rate of the electron macro pulse and laser amplification, there is no large barrier. The S-band rf accelerator can operate in high repetition rate and the laser amplifier can reach more than 100 kHz. Extrapolating our LUCX experimental result by the discussion above, 7.7×10^{11}photon/sec/10%bw. X-ray flux can be produced, which is comparable with 2nd generation synchrotron light sources and higher flux than the lab-scale micro focus X-ray tubes.

CONCLUSION

We are developing a compact LCS X-ray source using electron linac and burst mode optical enhancement cavity. Currently, we achieved 1000 bunch multi-bunch, 1 MW optical peak power storage in the cavity and 1.4×10^{8} photons/sec X-ray flux experimentally in LUCX facility. For further development, we discussed about the crab crossing of LCS, further development of the laser optical cavity and increasing the repetition rate. As a result, 7.7×10^{11}photon/sec/10%bw. X-ray flux would be achievable with linac based LCS X-ray source. Firstly, we will conduct a proof of principle experiment of crab crossing LCS and 6 mirrors optical enhancement cavity. Then we will try to upgrade our LUCX facility to be quite useful compact X-ray source.

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