DEVELOPMENT OF A COMPACT X-RAY SOURCE BASED ON LASER-COMPTON SCATTERING WITH A PULSED-LASER SUPER-CAVITY*

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Abstract

A compact and high quality x-ray source is required for various field, such as medical diagnosis, drug manufacturing and biological sciences. Laser-Compton based x-ray source that consist of a compact electron storage ring and a pulsed-laser super-cavity is one of the solutions of a compact x-ray source. Pulsed-laser super-cavity has been developed at KEK-ATF for a compact high brightness x-ray source. The pulsed-laser super-cavity enables to make high peak power and small waist laser at the collision point with the electron beam. Recently, 357MHz mode-locked Nd:VAN laser pulses can be stacked stably in a 420mm long Fabry-Perot cavity with 2.5kW average power in our R&D. On the other hand, we have succeeded to stack the pulsed amplified laser in the super-cavity. This indicates that the number of X-ray is multiplied due to the gain in the amplification system to synchronize the pulsed pump to the beam. In view of this successful result, we have started an X-ray generation experiment using a super-cavity and a multi-bunch electron beam at KEK-LUCX. Development of the super-cavity and the results of X-ray generation experiment will be presented at the conference.

INTRODUCTION

Recently, x-rays from synchrotron radiation (SR) is widely used and produced a number of results in various fields, for example, medical diagnosis, biological sciences, material sciences and so on. However, SR x-rays is generated by the huge facility as SPring-8, therefore the use is limited by the operation schedule and the number of users. On these backgrounds, a compact x-ray source has been strongly required and studied in many laboratories. In 1997, Huang and Ruth proposed a compact laser-electron storage ring (LESR) for electron beam cooling or x-ray generation.[1] In this proposal, each electrons and photons storage in storage ring and super-cavity, respectively, and therefore electrons and photons continuously interact and generate a high flux x-rays through the laser-Compton process.

We have developed a laser-wire beam profile monitor for measuring the electron-beam emittance at KEK-ATF. This monitor is based on the laser-Compton scattering with a laser light target. A thin and intense laser target is produced by exciting a Fabry-Perot optical cavity with a cw laser. [2] We proposed to apply this for pulsed-laser stacking to achieve the high peak power photon target. To use this scheme, the high peak power laser in super-cavity is scattered by the electron beam in storage ring continuously, and generate a high quality and high flux x-rays up to 10^{14}photons/sec.[3]

LUCX PROJECT IN KEK-ATF

At first, we are performing a proof-of-principle experiment of laser-Compton scattering between pulsed-laser super-cavity and multi-bunch electron beam before using compact ring at KEK-ATF. We call this linac based x-ray source, "LUCX" (Laser Undulator Compact X-ray source).

LUCX Electron Accelerator

Figure 1 shows the beam line layout of LUCX. As shown

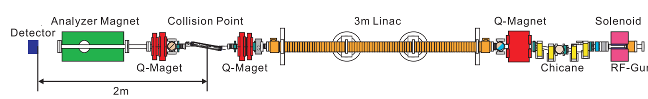

Figure 1: LUCX 40MeV beam line layout

in Figure 1, the accelerator consists of photo-cathode RF-Gun and 3m-long linac to generate and accelerate a multi-bunch electron beam up to 40MeV.[4] Laser-electron interaction point is located between the doublet quadrupole magnets to focus at the interaction point and to re-focus a diverging electron beam. At the interaction point, pulsed-laser super-cavity is installed at an angle of 20deg with beam line, which can produce a high peak and high average power photon target. The detail parameters of the super-cavity are described in following section. Downstream of the interaction point, electrons are bended toward the earth by a right-angle analyzer magnet to separate the electrons from the scattered photons and damped after an energy monitor system. According to the distance between interaction point and x-ray detector of about 2m and the aperture of Be window, x-rays within 10mrad scattered angle can be extracted from the vacuum. Using 100 bunches/train multi-bunch electrons and pulsed-laser super-cavity, the number of interaction is one hundred times larger than as usual.

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Expected X-ray Energy at LUCX

In LUCX, we are planning to generate 33keV high flux x-rays using 40MeV multi-bunch electrons and 1064nm laser light in the super-cavity. In medical application, around 33keV x-ray is used for a contrast diagnosis. 33keV is the energy of K-edge of a contrast medium, iodine (I). Figure 2 shows the estimated energy of x-rays at LUCX and attenuation coefficient of iodine. The blue line shows

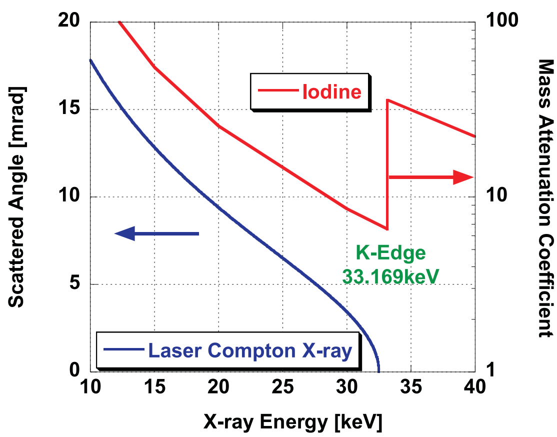

Figure 2: Laser undulator x-ray energy at LUCX

the energy of generated x-rays as a function of scattered angle, and the red line shows the attenuation coefficient of iodine. As shown in Figure 2, the energy of scattered photons is around 33keV, that attenuation of iodine is sharply changed (K-edge).

PULSED-LASER SUPER-CAVITY

Present Status of Super-Cavity

We have been developing the high finesse super-cavity to be used in this project.[5] In pulsed-laser case, the length of mode-locked cavity and super-cavity must be equal with less than nano-meter accuracy on more than 1000 finesse cavity.[6] Present status of our super-cavity system is shown in table 1.

Table 1: Present Status of Super-Cavity

Input Power	Finesse	Waist size	Power in Cavity	Enh. Factor
4.05W	1889.9	89.2μm	2.45kW	605

Finesse is measured by the decay method using pockels cells and waist size is measured by the phase advance between the two different cavity mode. These values are consistent with the design value of super-cavity. As shown in Table 1, we have already achieved over 600 enhancement and 2.45kW laser power in the super-cavity which is measured by the transmitted power from the cavity and transmittance of output mirror. For the stable operation of super-cavity, we performed a long running test of super-cavity with feedback. As a result of this, it is confirmed that our super-cavity system can operate over 10 hours without failing the resonant feedback.

Burst Mode Super-Cavity

On the other hand, we devised and developed a ”burst mode super-cavity”, that is a technique of pulsed amplified laser stacking in the super-cavity. Figure 3 shows a diagram of burst mode cavity and Figure 4 shows the timing diagram of burst mode cavity and LUCX multi-bunch electron beam. As shown in Figure 3, mode-locked laser is

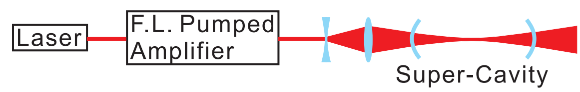

Figure 3: Diagram of Burst Mode Super-Cavity

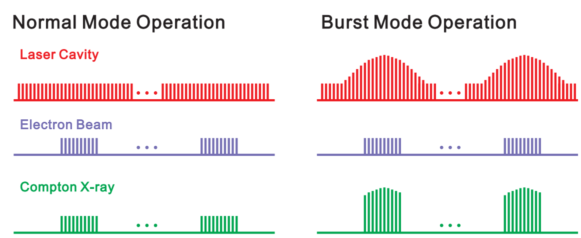

Figure 4: Timing Diagram of Burst Mode Cavity and Multi-bunch Electron Beam

amplified by the flash lamp pumped (pulse flash pumping) amplifier before injected to the super-cavity. To inject a pulse-amplified laser, laser power in cavity has high peak power at the pumping timing (Figure 4) and to synchronize a pumping timing to the electron beam timing, the number of x-ray will be enhanced by the gain of laser amplifier.

The measured parameters of burst mode super-cavity is shown in Table 2.

Table 2: Parameters of Burst Mode Super-Cavity

Amp Gain	Finesse	Waist size	Peak Power in Cav.
70	878.5	30.3μm	40kW

We have already succeeded in the burst mode cavity operation and achieved 40kW peak power in the cavity. In the burst mode test, laser induced mirror damage occurs due to the laser induced plasma which caused that the peak power is too strong on the mirror surface. Therefore, we changed the cavity mirrors to expand the laser spot size on the mirror, this is because that the finesse and waist size are different from ”normal mode super-cavity” (Table 1)

X-RAY GENERATION EXPERIMENT AT LUCX

Expected Number of X-rays at LUCX

To use burst mode super-cavity for laser-Compton collision at LUCX, the number of produced x-ray is multiplied by the peak power in the cavity. Expected number of x-ray is 4.5×10^4Photons/train in total. As the results of background measurement, this value will be enough for x-ray detection. Figure 5 shows the setup of the x-ray detector at LUCX. Detection system consists of 10mm radius collimator and scintillation detector. We produced a 150μm thick LYSO scintillation detector to detect x-ray signal, which is not sensitive for high energy photons and has relatively high time resolution (40ns). According to this detector setup, the aperture of detector is about 2.5mrad and expected number of detected x-ray is 8.0×10^2Photons/train.

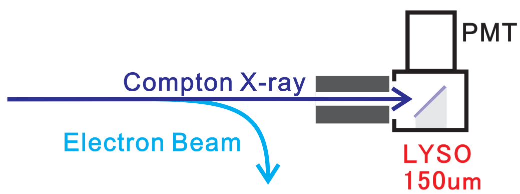

Figure 5: X-ray Detection System at LUCX

Laser-Compton X-ray Detection

We have already performed an x-ray generation experiment using a burst mode cavity, multi-bunch electron beam and a scintillation detector (Figure 5). The experimental results of x-ray detection are shown in Figure 6 and 7 As shown in Figure 7, the number of x-ray is certainly proportional to the laser power. On the other hand, Figure 6 shows the timing cross correlation between an electron beam and a laser pulse, to scan the laser timing at the collision point. The gaussian fit of the experimental result is also appeared in the figure (dotted line) and the rms of fitted line is 0.97deg (7.5ps) which is consistent of an electron bunch length. These two results indicate that this signal is exactly produced by the laser-Compton scattering between the multi-bunch beam and the pulsed-laser super-cavity.

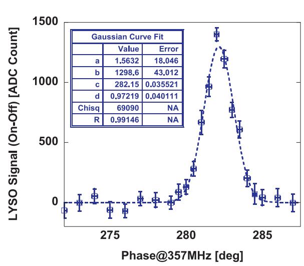

Figure 6: Timing Correlation Measurement

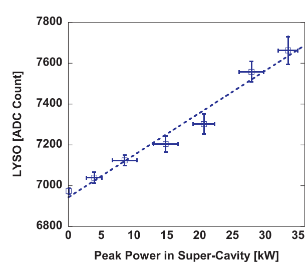

Figure 7: Laser Power Correlation Measurement

The waist size of the laser target is precisely determined by the mirror curvature and the cavity length in super-cavity, so that to scan the position, measured x-ray profile can be used as the electron beam size measurement. Figure 8 shows the result of laser target position scan. The gaussian fit of the result is shown by dotted line and the rms of x-ray profile is 77.6μm. As described in previous section, laser waist size is measured as 30.3μm. To consider the laser waist, beam size of the electron beam is calculated to 71.4μm.

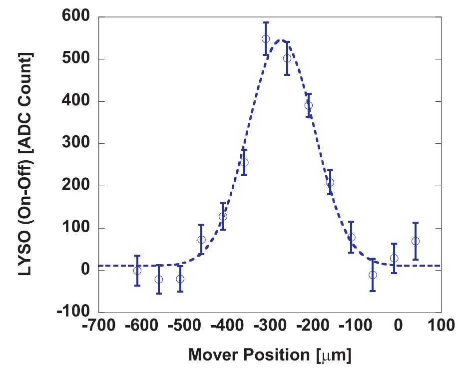

Figure 8: Vertical Laser Position Scan (Electron Beam Size Measurement)

CONCLUSIONS

We plan to compact x-ray source using super-cavity for laser and storage ring for electrons. At first, proof-of-principle experiment of multi-bunch electrons and super-cavity laser light is performing at KEK-LUCX.

Pulsed-laser super-cavity has been developing and the storage laser power of 2.45kW is already achieved using 1900 finesse super-cavity. Burst mode super-cavity is also developing for linac base compact x-ray source. Using burst mode super-cavity, peak power of 40kW has been achieved. We succeeded in detecting a x-ray signal generated between burst mode pulsed-laser super-cavity and multi-bunch electron beam at LUCX, and confirmed the x-ray is certainly generated from the process of laser-Compton scattering by observing the correlation of laser-electron crossing.

In near future, we will perform the x-ray energy measurement by bragg reflector and x-ray detection bunch by bunch for more understanding the multi-bunch effect.

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