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LASER-COMPTON SCATTERING X-RAY SOURCE BASED ON NORMAL CONDUCTING LINAC AND OPTICAL ENHANCEMENT CAVITY *

K. Sakaue†, WIAS, Waseda University, Tokyo, Japan
M. Washio, RISE, Waseda University, Tokyo, Japan
S. Araki, M. Fukuda, Y. Honda, N. Terunuma, J. Urakawa, KEK, Ibaraki, Japan

Abstract

We have been developing a compact X-ray source via laser-Compton scattering (LCS) at KEK-LUCX (Laser Undulator Compact X-ray source) facility. The LUCX system is based on S-band normal conducting linac with an energy of 30 MeV and optical enhancement cavity for photon target. As a photon target, we invented a burst mode laser pulse storage technique for a normal conducting linac, which enables to store the high power laser pulses at the timing of electron bunches. The peak storage power exceeds to more than 250 kW with 357 MHz repetition. Electron linac is under operation with multi-bunch mode, 1000 bunches/train with 600 pC charge in each bunches. We have succeeded to produce 1000 pulse/train LCS X-ray train. Combining high repetition rate electron linac and burst mode optical enhancement cavity, more than 10^9 ph./sec/10% b.w. flux would be possible. In this conference, the introduction of our test facility LUCX, recent experimental results, and future prospective including normal conducting LCS X-ray source will be presented.

INTRODUCTION

An X-ray generation method based on laser-electron Compton scatterings (LCS) is one feasible technique for a high brightness compact X-ray source. It utilizes a process in which energetic electrons scatter elastically a target laser photons, with an energy transfer from the electrons to the photons. The advantages of LCS are compactness thanks to its short undulation period by laser electric field[1], high brightness caused by the focused electrons and photons, and relatively large divergence angle due to small Lorentz factorγ. For instance, a 30 MeV electron beam with the laser wavelength of ~ 1 μm can produce 15 keV X-rays. This advantage has propelled worldwide laboratories to develop compact LCS X-ray sources with a brightness equivalent to the second generation light sources.

We have been developing a compact X-ray source based on an optical enhancement cavity operated with a burst amplifier[2] and a normal conducting pulsed linac. The pulse X-ray trains were already observed using a multi-bunch electron beam and an optical enhancement cavity[3]. Also, we have already tried to take X-ray images by LCS X-rays[4]. Recently, we have upgraded both accelerator system and enhancement cavity in order to increase the photon flux.

The paper describes the recent status of our accelerator and optical enhancement cavity, especially focused on the burst mode operation of enhancement cavity system, experimental results of LCS X-ray generation and feasibility study of our X-ray source extrapolating our recent results.

EXPERIMENTAL SETUP

In this section, we mention about our LUCX facility, based on normal conducting linac and optical enhancement cavity.

Multibunch Normal Conducting Linac

The LUCX facility is located inside the housing of the KEK Accelerator Test Facility (ATF). Firstly, we show the accelerator layout in Fig.1 The LUCX accelerator is an S-band, normal conducting rf linac operating with 12.5Hz pulsed electron beam. The electron bunches were produced by 3.6cell photo-cathode rf electron gun and accelerated up to 30MeV by 12cell standing wave booster linac. This linac can produce multibunch electron beam by irradiating the UV laser pulses with high repetition rate. Detail of multibunch beam handling is described in [5]. Successful approach of multibunch beam manipulation by rf amplitude/phase modulation allows us to produce 1000 electron bunch with 2.8ns bunch space on one rf pulse. The LCS interaction point is located at the center of optical enhancement cavity. The multibunch electron and optically enhanced laser pulses were interacted with each other inside the optical cavity. After interacting with laser, electron bunches are separated from the LCS X-ray by bending magnet and transported to the beam dump.

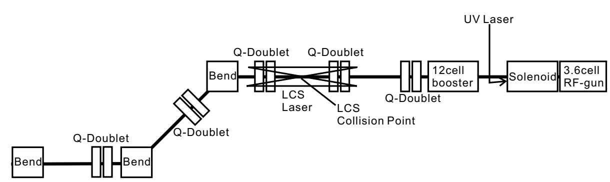

Figure 1: Facility layout of LUCX.

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† kazuyuki.sakaue@aoni.waseda.jp

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Burst Mode Optical Enhancement Cavity

Optical enhancement cavity is an open resonator for laser wave. It makes possible to enhance the incident laser power inside the cavity by stacking the laser pulses. The cavity enhances the laser power by stacking the laser pulses in same phase over thousand of times thus the cavity length has to be precisely tuned less than nanometer accuracy. The optical cavity and laser oscillator path length can easily be fluctuated more than nanometer by the external disturbance such as acoustic noises and mechanical vibration, therefore we built a fast feedback system in order to keep resonance at all time. In other words, the optical enhancement cavity needs continuous injection of laser light to keep resonance. However, as we mentioned above, our accelerator is based on normal conducting pulsed technology so the electrons come to the interaction point with pulsed temporal structure. It is not efficient for optical enhancement cavity that the only 10^{-5} laser pulses can interact with electron bunch. Therefore, we invented the burst mode operation of optical enhancement cavity for normal conducting pulsed linac. The schematic of burst mode operation is illustrated in Fig.2. The seed laser is a ps pulsed mode-locked laser.

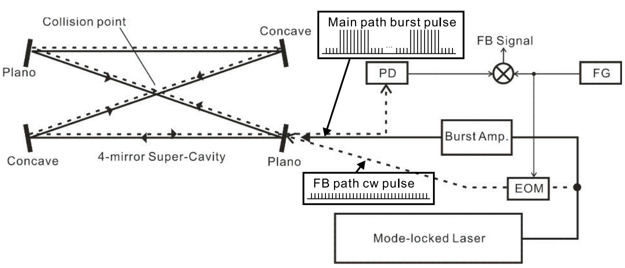

Figure 2: Schematic of burst mode optical enhancement cavity.

The seed is separated into two part, one is for main pulses interact with the electron bunch and the other is for the feedback of optical enhancement cavity. The main pulses pass the burst amplifier system with gain of more than one thousand. It is a pulsed LD pumped amplifier module so the incident laser pulses are amplified at the timing of electron beam bunches, and the power inside the optical cavity is also increased thanks to the enough amplified duration for filling the optical cavity. The feedback signal, observing a resonant condition of optical cavity, is produced by separated part of seed laser and injected to the cavity in opposite way. The advantage of this feedback system is complete separation of main path and feedback path. The large gain of burst amplifier prevent us to keep the resonance of cavity, but this scheme can solve this phenomenon. Thanks to this burst mode scheme, we succeeded in storing more than 250kW laser power inside the cavity as shown in following Tab.1.

Here the parameters of electron and laser at the collision point are summarized in Tab.1. The electron beam and laser have same pulse spacing, thus the all bunches interact with laser pulses stored in the optical cavity. Expected LCS X-ray energy is 9-10keV at the center.

Table 1: Electron Beam and Laser Pulse Parameters

Quantity	Value
Electron beam	
Energy	24 MeV
Charge	0.6 nC/bunch
Number of bunches	1000/train
Bunch spacing	2.8 ns
Beam size (rms)	80/50 μm (H/V)
Bunch length	15 ps (FWHM)
Repetition rate	1.56-12.5 Hz
Laser pulse	
Wavelength	1064 nm
Pulse energy	0.7 mJ
Peak power	250 kW
Cavity finesse	335
Pulse spacing	2.8 ns
Spot size (rms)	89/85 μm (H/V)
Pulse duration	7 ps (FWHM)
Colliding angle	7.5 deg

RESULTS AND DISCUSSIONS

LCS X-ray generation experiment was performed at LUCX with upgraded system as described above. After the evaluation of LCS X-ray detection and position adjustment by MCP (Micro-Channel Plate) detector, we tried to generate 1000 pulse LCS X-ray generation. The resulting X-ray waveforms are plotted in Fig. 3. The waveforms plotted in Fig. 3 are the subtraction of background waveform from the raw waveform. It is clear that the 1000 bunch case observed the X-ray pulses during 2.8 μs i.e. 1000 pulses. According to this figure, we consider that the all electron bunch can interacted with laser pulses in-

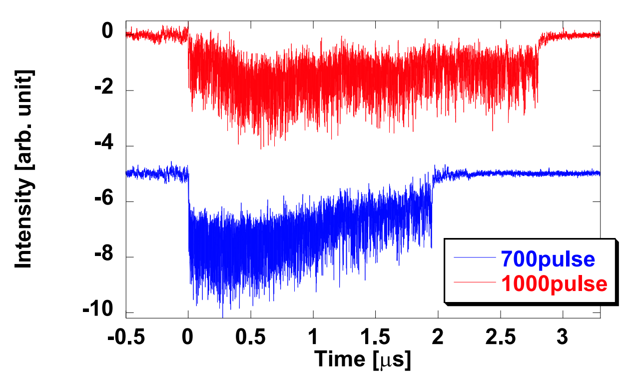

Figure 3: 700 and 1000 pulse X-ray train detected by MCP.

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side the cavity. However, comparing with 700 bunch operation, the X-ray intensity profile was not uniform in 1000 bunch operation. Thus we thought that it is not perfectly interacted at the collision point due to such as position difference or timing difference caused in the multibunch handling processes. The calculated number of X-ray photons were about 4×10^6ph./train/totalband (4×10^5ph./train/10% bandwidth). It should be noted that our MCP was not perfectly calibrated at this energy range so we think this number has 50% error.

CONSIDERATION FOR FURTHER DEVELOPMENT

According to the LCS X-ray generation result above, we can design the further high brightness, high flux and compact LCS X-ray source. There are two way of design directonality, one is concentrating for high average flux for accumulating detection and the other is for high pulse flux for single shot measurement. First we show the former case in following Table 2, and later we will discuss about the problem for single shot LCS X-ray source. As shown in Table 2, increasing the repetition rate and focusing laser/electron will produce X-ray flux of more than 10^9/sec/10% b.w.. It is clear that the electron beam have to be lower emittance compared with current status in order to achieve small spot size. We consider that the beam emittance can be reduced by optimizing the cathode irradiating UV laser. For increasing the repetition rate to 1kHz, it has already available for laser system, our burst amplification system can extend to higher repetition rate. Concerning about the accelerator, the rf system should be improved the repetition rate, however, the S-band klystron can increase the repetition rate and the pulse power modulator would also increase the repetition rate by using semiconductor switches. It seems possible to build such a LCS X-ray source in near future.

Table 2: Design for High Average Flux LCS X-ray Source

	Present	Design
Pulse space [ns]	2.8	2.8
Pulse rep. [Hz]	12.5	1000
Ele. size [μm]	80/50	30/30
Photon size [μm]	89/85	80/30
Ave. flux [/sec/10% b.w.]	5×10^6	1.3×10^9

Also, for high pulse flux LCS design, the electron bunch in train is approaching the limit for normal conducting accelerator. We have to improve the laser power for single shot measurement. Limitation for laser power in the optical cavity is the damage thresihold of optical cavity mirrors, which determined by W/cm^2. Thus we have to enlarge the laser profile on the mirror. It seems possible to enlarge the profile 10 times larger, i.e. 10 times higher power would be achievable in current setup. However, it is not enough for single shot measurement so that the cavity system have to be improve to achieve higher laser power storage in the optical cavity. We would like to note that the improvement of laser power improves not only X-ray flux but also the Signal-to-Noise ratio of X-ray source due to the no increase of bremsstrahlung X-rays.

SUMMARY

In conclusion, we have upgraded our LUCX LCS X-ray system both accelerator and laser. The resulting X-ray flux was 4×10^5 ph./train in 10% bandwidth due to the successful result of 1000 bunch multibunch generation. Extrapolating this result, we design the high average LCS X-ray source with more than 10^9/sec/10% b.w. flux. It could be possible to build without any barriors. For high pulse flux LCS X-ray sources, we have to improve the optical enhancement cavity system further. The directionality of improvement is clear that the we will perform the higher laser power storage in the optical enhancement cavity.

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