DEVELOPMENT OF PULSE LASER SUPER-CAVITY FOR COMPACT HIGH FLUX X-RAY SOURCES*

K. Sakaue,† M. Washio, Waseda University, Tokyo, Japan
S. Araki, M. Fukuda, Y. Higashi, Y. Honda, M. Takano, T. Taniguchi, J. Urakawa, KEK, Ibaraki, Japan
N. Sasao, Kyoto University, Kyoto, Japan
H. Sakai, University of Tokyo, Chiba, Japan

Abstract

Pulsed Laser Super-Cavity has been developed for compact high brightness x-ray sources based on Laser Compton Scattering at KEK-ATF. The Pulse Laser Super-Cavity increases the laser power and stably makes small laser beam size at the collision point with the electron beam. Recent results of Super-Cavity and multi-bunch electron beam indicate the possibility of the application to K-edge digital subtraction angiography as the compact high flux X-ray source. Therefore, we have planned a compact hard x-ray source using 50MeV multi-bunch electrons and a pulse stacking technology with 42cm Fabry-Perot cavity. The photon flux is multiplied with the number of bunches by using multi-bunch beam and Super-Cavity. We have finished the constraction of 50MeV linac and started operation in spring 2006. Development of the Super-Cavity and plan of compact x-ray source will be presented at the conference.

INTRODUCTION

Recently, x-rays from syncrotron radiation (SR) is 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 like SPring-8, therefore the use is limited by the operation schdule and the number of users. On these backgrounds, a compact x-ray source has been storongly 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 are storaged in storage ring and super cavity, respectively, and therefore electrons and photons continuously interact and generat 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 for pulse 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]

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). We planned to generate 33keV high flux x-rays using about 50MeV electrons and 1064nm laser light. In this paper, our compact x-ray source project, LUCX (Laser Undulator Compact X-ray source) will be reported.

PLAN OF COMPACT X-RAY SOURCE

Schematic diagram of our compact x-ray source project is shown in Fig.1.

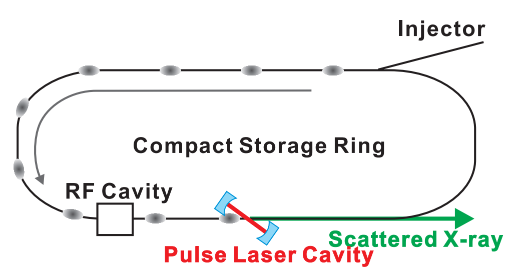

Figure 1: Schematic diagram of compact x-ray source

This source mainly consists of a compact storage ring and a pulse laser super-cavity as described in fig.1. Pulse laser in super-cavity is scattered off the electron beam in storage ring resulting in production of high flux x-rays. In super-cavity, mode-locked pulse laser power is enhanced by the phase matching so as to produce the high peak power photon target. To storage both electrons and photons and use repeatedly, number of collision is over 3millions. Therefore, high flux x-ray can be generated using this scheme.

At first, proof-of-principle experiment of laser Compton scattering between pulse laser super-cavity and muti-bunch electron beam before using compact ring is to be performed as Fig.1.

Multi-bunch electron beam generation at LUCX

A 100bunches/train multi-bunch electron beam has been already produced using laser photo-cathode RF-gun with

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† kazu-kazu-kazu@suou.waseda.jp

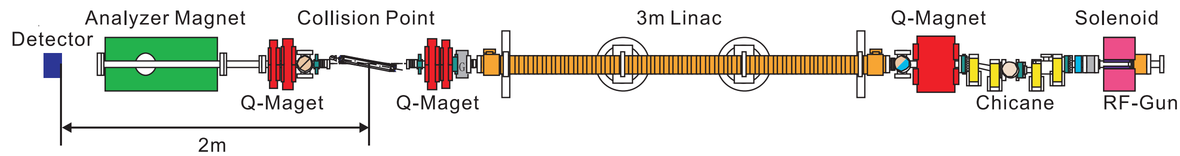

Figure 2: LUCX 50MeV beam line layout

Cs_2Te cathode and multi-pulse laser system at LUCX accelerator in KEK-ATF.[4] Beam line is now upgraded to accelerate up to 50MeV as described in Fig.2.

As shown in Fig.2, 3m-long linac tube has been installed to accelerate a multi-bunch electrons. Laser-electron interaction point is located between the doublet quadrupole magnet to focus at interaction point and to re-focus the diverging electron beam. In this point, pulse laser super-cavity will be installed after the first beam production experiment. 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 detected. The interaction of 100 bunched/train multi-bunch electrons and pulse laser super-cavity results in the high flux x-rays about one hundred times larger than as usual. At present, RF processing of a waveguide and a linac tube is almost finished, and we will generate an electron beam in this summer.

Expected x-rays at LUCX

In Tab.1, parameters of the interaction particles, electron beam and laser beam are described.

Table 1: Parameters of interaction particles at LUCX

Electron		Laser	
RF Rep.	12.5Hz	Crystal	Nd:VAN
Energy	50MeV	Wavelength	1064nm
Pulse Rep.	357MHz	M.L. freq.	357MHz
Bunch Num.	100/train	Enhancement	1000
Charge	2nC/bunch	Power	6kW
Bunch length	10ps	Pulse width	7ps
Beam size	X:64μm	Waist size	X:85μm
	Y:32μm		Y:85μm
Collision angle		20degrees	

Electron beam parameters are the calculated value by SAD. Laser beam parameters, enhancement factor and waist size are in accordance with the present status of pulse laser super-cavity, which will be described in next section, and the matching efficiency of super-cavity and pulse laser is assumed 100%, that indicates that all input laser power go into the super-cavity. It is noted that bunch length and pulse width is in FWHM, and beam size and waist size is in RMS.

Expected x-ray energy is shown in Fig.3. Fig.3 shows

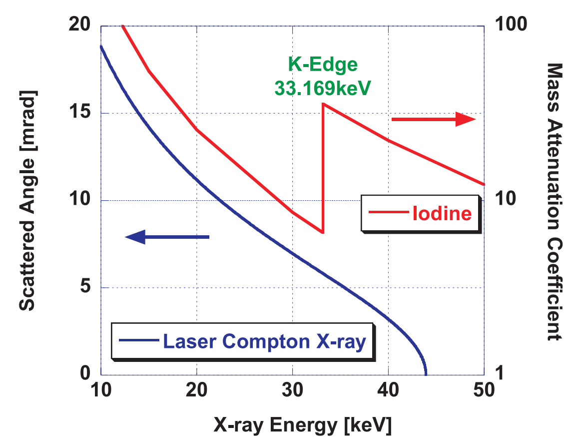

Figure 3: Laser undulator x-ray energy at LUCX

the energy of x-rays at LUCX estimated by the parameters of Tab.1 and attenuation coefficient of iodine. The blue solid line shows the energy of generated x-rays as a function of scattered angle, and the red solid line shows the attenuation coefficient of iodine. As shown in Fig.3, the energy of scattered photons is around 33keV, that attenuation of iodine is sharply changed (K-edge).

On the other hand, the number of x-rays is also estimated by Tab.1. Total number of photons is about 400, and assuming that the detector with 10mrad aperture, about 200 photons can be detected, that is the half of the total generated photons. To take parameter of LUCX accelerator, the number of bunches of 100bunches/train and RF repetition of 12.5Hz, into consideration, we will detect about 2.5×10^5photons/sec.

In this summer, we will make an effort to achieve these paramaters as Tab.1 and generate 2.5×10^5x-rays/sec.

PULSE LASER SUPER-CAVITY

Coherent storage of a laser light in an optical cavity has been commonly used with a CW laser beam.[2] We have developing the high finesse optical cavity to be used in this project.[5] In pulse laser case, the length of mode-locked cavity (L_{laser}) and super-cavity (L_{cav}) should be equal with accuracy as follows. This figure shows the calculated resonant peak of each enhancement factors, 100, 500 and 1000. In the case of enhancement=1000, resonant width is

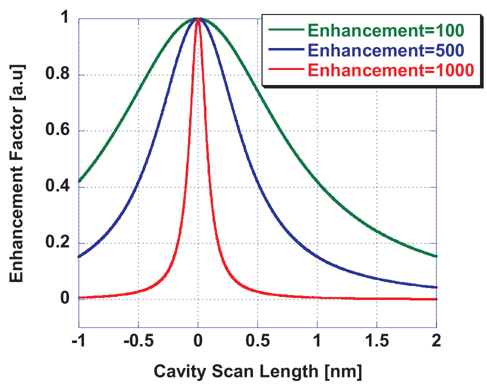

Figure 4: Resonant peak of each enhancement factors

less than 1.7$\mathring{A}$ (FWHM), thorefore, the difference between two cavities must be less than 1.7$\mathring{A}$.

$$| L_{laser} - L_{cav} | \ll 1.7\mathring{A} \tag{1}$$

This strict requirement is due to the phase matching of laser light wave as eq.(2)

$$L_{cav} = n\frac{\lambda}{2} \qquad (n : integer) \tag{2}$$

Because of this strict requirement, we use piezo actuator to control both cavity length.

Current Results of Pulse Laser Cavity

We reported about a pulse laser super-cavity at EPAC'04 [5], so that development of the super-cavity from Ref[5] will be reported in this paper. In Ref[5], confirmation of pulse laser stacking in optical cavity that consist of two concave mirrors with reflectivity of 99.9%. The development is to specify the source of cavity length jitters and their reduction. As a result of this study, we have suceeded in closing the feedback loop of cavity length around resonance, that enehancement factor is 1000.

The major jitters affective to the resonance are relatively high frequency jitters from accoustic noises, and the phase noises in the reference signal of the modelock laser cavity Phase Locked Loop (PLL) that controls the pulse repetition. FB speed of our system is limited by the natural frequency of piezo, that frequencies are about 7kHz in modelock cavity and about 3kHz in super-cavity.

Jitters from accoustic noise have a relatively high frequency (1∼2kHz) that is hardly to be suppressed because of the limitation of FB speed. These accoustic noises should be reduced as small as possible, therefore we install a soundproof materials around the system and a dampers that effective on a kHz order vibration. After these installation, accoustic noises are reduced about ten times less than as before.

Jitters from phase noise have a broad frequency and a large amplitude compare with the resonant peak (Fig.4) The problem should be that FB speed of modelock laser cavity is faster than that of super-cavity, consequently phase noise jitter cannot be suppressed by the super-cavity FB. To reduce this phase noise jitters, we adjusted the frequency bandwidth of PLL circuit as low as not affective.

Fig.5 shows the result of feedback test on enhancement=1000 cavity after the jitter reduction. Left picture

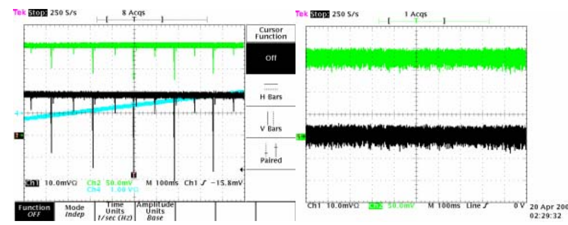

Figure 5: Feedback test of enhancement=1000 cavity

shows the error signal for FB when the cavity length is scanned by piezo, and right picture shows the laser power jitter in super-cavity when the FB loop is closed. As shown in Fig.5-right, a laser power jitter is about 15% in peak-to-peak, that can be used for x-ray generation.

DISCUSSIONS

Present status of pulse laser super-cavity is shown in Tab.2. These values in Tab.2 are the measured value. The

Table 2: Current status of pulse-laser cavity

Frequency Length	Finesse Reflectivity	Waist size Curvature	Laser power @injection
357MHz 420mm	$\sim$ 3000 $\sim$ 99.9%	170μm 250mm	6W @357MHz

most important parameter of laser power in super-cavity is now developing, the matching efficiency and new FB system that can control the cavity length on resonace[6].

CONCLUSION

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 will be performed in this summer. Pulse laser super-cavity have been developing at KEK-ATF. Useful cavity with enhancement factor 1000 is achieved.

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