3-DIMENSIONAL BEAM PROFILE MONITOR BASED ON A PULSE STORAGE IN AN OPTICAL CAVITY FOR MULTI-BUNCH ELECTRON BEAM*

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Abstract

We have been developing a pulsed-laser storage technique in a super-cavity for a compact X-ray sources. The pulsed-laser super-cavity enables to make high peak power and small waist laser at the collision point with the electron beam. Recently, using 357MHz mode-locked Nd:VAN laser pulses which stacked in a super-cavity scattered off a multi-bunch electron beam, we obtained a multi-pulse X-rays through the laser-Compton scattering. Detecting X-rays pulse-by-pulse using high-speed detector makes it possible to measure the 3-dimensional beam size with bunch-by-bunch scanning the laserwire target position and pulse timing. This technique provides not only the non-destructive beam profile monitoring but also the measuring of bunch length and/or bunch spacing shifting. In our multi-bunch electron linac, the bunch spacing narrowing due to the electron velocity difference in the train at the output of rf-gun cavity was observed. Principle of 3-dimensional laserwire monitor and the experimental results of multi-bunch electron beam measurement will be presented at the conference.

INTRODUCTION

We have been developing a laser storage technique in an optical cavity. At the beginning, a laserwire beam profile monitor was established as non-destructive beam profile monitor at KEK-ATF damping ring using cw laser storage. Laser storage in an optical cavity enhances the laser power and enables to make small waist laser stably at the center of the optical cavity. This monitor was successfully demonstrated to measure the extremely low emittance beam produced in ATF damping ring[1].

On the other hand, we have been also developing a pulsed-laser storage technique for a compact X-ray source based on laser-Compton scattering. This compact X-ray source was firstly proposed by Huang and Ruth in 1997 for electron beam cooling[2]. 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 proposed to apply the laserwire technique for pulsed-laser stacking to achieve the high peak power photon target. To use this super-cavity and an electron storage ring, the high peak power laser in super-cavity is scattered by the electron beam continuously, and generate a high quality and high flux X-rays up to 10^{14}photons/sec[3]. As the first step of this proposal, we are performing a proof-of-principle experiment of laser-Compton scattering using pulsed-laser super-cavity and multi-bunch electron beam. We call this linac based X-ray source, ”LUCX” (Laser Undulator Compact X-ray source).

We have already succeeded in detecting pulse-train X-ray produced by laser-Compton scattering. When the X-ray generation experiment at LUCX project, we found that this pulsed-laser storage cavity can be used not only for transverse beam profile monitor but also longitudinal profile measurement and bunch spacing monitoring. As the electron linac produces higher current, variation of bunch spacing have been appeared and affected to produce a high quality electron beam. For example, the variation of bunch spacing causes accelerating phase difference for each bunches in the acceleration structure and then beam emittance and energy spread are degraded. In these backgrounds, we propose three-dimensional profile monitor based on a pulse storage optical cavity : the principle of this monitor and experimental results of profile measurement will be reported in this paper.

LUCX ELECTRON ACCELERATOR

LUCX multi-bunch electron linac is located by the side of the KEK-ATF accelerator. Figure 1 shows the beam line layout of LUCX. As shown in Figure 1, the accelerator

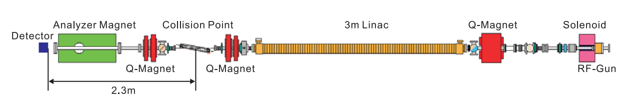

Figure 1: LUCX Electron Beam Line

consists of a photo-cathode RF-Gun and 3m-long linac to generate and accelerate a multi-bunch electron beam up to 43MeV. Beam loading effect in the accelerating structure is compensated by adjusting the timing of rf pulse and so the energy difference in a bunch train is compensated less than 1%[4]. It is noted that LUCX accelerator has only one klystron for exciting rf-gun and accelerating tube, thus the

* Work supported by a Grant-In-Aid for Creative Scientific Research of JSPS (KAKENHI 17GS0210) and a Quantum Beam Technology Program of JST

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beam loading is compensated totally in both accelerating structures. The parameters of a multi-bunch electron linac is shown in Table 1.

Table 1: Parameters of Multi-bunch LINAC

Charge	Energy	Num. Bunch	Bunch Space
0.4nC	43MeV	100/Train	2.8nsec

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 from the scattered photons and damped after an energy monitor system. According to the distance between interaction point and X-ray detector and the aperture of Be window, X-rays within 10mrad scattered angle can be extracted from the vacuum. An X-ray detector is located after the Be window and we chose a Micro-Channel Plate (MCP : F2224-21 Hamamatsu Photonics K. K.) because of its time resolution, which can measure the X-ray pulse-train separately in this experiment.

BURST PULSE STORAGE IN AN OPTICAL CAVITY

We have been developing the high finesse super-cavity to be used for LUCX project. In pulsed-laser storage 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 so that each cavity lengths have to be feedbacked. We have already succeeded in stacking 2.5kW power in cavity and operating more than 1900 finesse super-cavity system over 10 hours without failing the resonant feedback[5].

Taking over this successful result, we devised and developed a "burst mode super-cavity", that is a technique of pulsed amplified laser stacking in the super-cavity. This technique provides high power pulse when the electron bunch-train comes to the interaction point, that is suitable for linac electron beam. Figure 2 shows the timing diagram of burst mode cavity and LUCX multi-bunch electron beam. To inject a pulse-amplified laser pulses, laser power in cavity has higher peak power at the pumping timing (Figure 2) 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. We have already succeeded in the burst mode cavity operation and achieved 40kW peak power in the cavity.

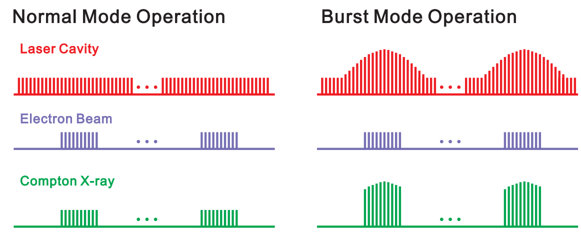

Figure 2: Schematic of Burst Mode Super-Cavity

Table 2: Parameters of Burst Mode Super-Cavity

Pulse Duration	Finesse	Waist size	Power in Cav.
7-psec (fwhm)	878.5	30.3μm	40kW

EXPERIMENTAL RESULTS

Pulse-train X-ray Detection

In LUCX, we are expecting to generate 33keV 100 pulses/train X-rays using 43MeV multi-bunch electrons and 1064nm laser light. We have already succeeded in generating and characterizing the laser-Compton X-rays[6]. Using MCP detector, the X-ray pulse-train can be measured as shown in Figure 3. This figure was obtained by the background subtraction from X-ray with background waveform. 100 X-ray pulses were separately detected in 280nsec, which is consistent with the electron bunch train.

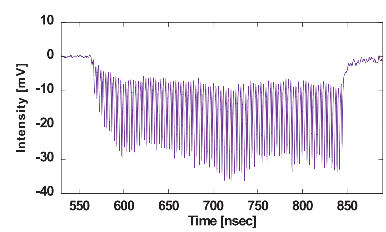

Figure 3: Pulse-Train X-rays Detected by MCP

Demonstration of Profile Measurement

As shown in Figure 3, the pulse-by-pulse X-ray intensity can be obtained using the MCP detector. Therefore, the bunch-by-bunch electron beam profile measurement can be achieved by measuring the pulse X-ray intensity as the colliding laser position or timing is scanned. This method will provide not only a bunch-by-bunch electron beam profile, but also information on the micro-pulse distribution in the macro-pulse (bunch train).

We scanned the laser position vertically and horizontally and scanned the collision timing for measurement of the multi-bunch electron beam profile. The results of laser position scanning are shown below. The results of vertical position scanning and horizontal scanning are shown in Figures 4 and 5, respectively.

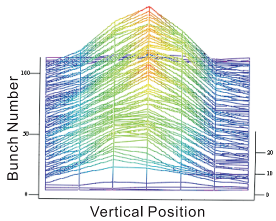

Figure 4: Vertical Position Scan

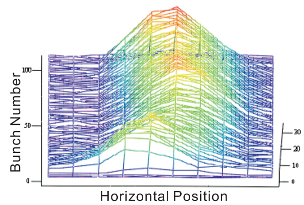

Figure 5: Horizontal Position Scan

As shown in Figure 4, the optimum colliding position was almost the same in all of the bunches, but the X-ray intensity from the former bunches was lower than that from the latter bunches. This phenomenon was caused by the bunch spacing narrowing, as shown in Figure 5. The collision timing and horizontal position were coupled because of their geometrical setup.

Figure 5 shows the result of horizontal scanning. The optimum horizontal position differed for each bunch. When convergence isn't strong, the horizontal position shift Δh can be compensated by collision timing shift Δt as:

$$\Delta h = (\beta c \Delta t + \cos\theta)\sin\theta \quad (1)$$

where β is the Lorentz factor, c is light velocity, and θ is the collision angle. Thus, the optimum position shift is regarded as the shift of the optimum collision timing.

The result of the bunch-by-bunch timing profile measurement is shown in Figure 6. Profiles almost identical

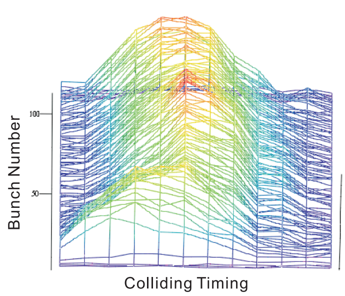

Figure 6: Collision Timing Scan

to those shown in Figure 5 appear in Figure 6. The LUCX accelerator uses only one klystron to excite both the rf-gun cavity and accelerating tube, as described in previous section. Further, the beam-loading effect is compensated for using both the rf-gun cavity and accelerating tube. Thus, the electron bunches have slightly different energy at the output of the rf-gun cavity. This causes velocity dispersion, and bunch spacing shifting occurs in regions with relatively low energy on the order of several MeV. In the case of LUCX, the former bunches have slightly lower energy than the latter bunches, hence the bunch spacing is narrowed by the velocity dispersion. Figure 7 illustrates the calculated difference in the accelerating tube arrival time in the bunch train. A difference of about 10psec is calculated in the whole bunch train. The horizontal axis of Figure 7 is

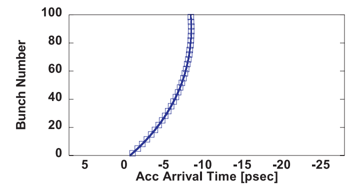

Figure 7: Acc. Arrival Time Calculation

same with Figure 6, as it is clearly appeared that the experimental results show good agreement with calculation.

DISCUSSIONS

We demonstrated a 3-dimensional profile monitor using pulse storage optical cavity. The transverse and longitudinal profile can be measured for each bunches in multi-bunch electron beam. Further more, the bunch spacing narrowing was observed in the LUCX multi-bunch electron beam due to the velocity dispersion.

Up to now, this experiments were performed using X-ray generation setup. When we wish to measure the transverse and longitudinal profile separately, the collision angle of electron and laser pulse should be 90deg and the system have to be have two optical cavity for horizontal and vertical directions. Figure 8 shows the schematic of 3D profile

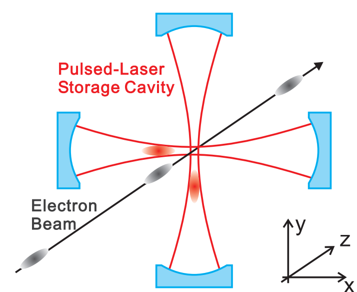

Figure 8: Schematic of 3D Profile Monitor

monitor. Using vertical optical cavity, the horizontal profile can be measured without the coupling with timing as shown in Eq. 1. In addition, this monitor has feasibility for measuring an ultra-fast bunch length by storaging an ultra-fast pulses in the optical cavity.

Upgrades in this beam profile monitor system will make it possible to measure not only 3-dimensional micro-bunch beam profiles, but also the distribution of the micro-bunch in the macro-bunch.

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