DEVELOPMENT OF KICKER MAGNET FOR GENERATION OF SHORT PULSE SYNCHROTRON RADIATION

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Abstract

We have developed a kicker magnet system to generate short pulsed synchrotron radiation in the SPring-8 storage ring. One method of generating a short pulsed synchrotron radiation is collimating a synchrotron radiation coming from a tilted electron bunch with a slit. For this purpose, we used a pulsed magnet to kick an electron bunch. A head-tail oscillation of the kicked electron bunch is induced due to non-zero vertical chromaticity. The developed kicker magnet system can generate a pulsed magnetic field of about 5.7 mT within the 2.6 μs in a vertical direction to an electron bunch at a repetition rate of 1 Hz. With the kicker magnet system, we successfully observed a bunch profile which leans about 2 mm between head and tail position by using a visible streak camera. And, we also observed the sliced synchrotron radiation with a reduced bunch length of 7 ps by using an X-ray streak camera.

INTRODUCTION

In recent years, X-ray with shorter pulses are desired to measure fast dynamic process exploration with better resolution by material structure physics user. The required pulse width to take a snapshot of the dynamic process of atoms, such as atomic vibration period during chemical reaction is on the order 100 fs. For this request, there are many schemes to produce shorter X-ray pulses, for example, based on laser-produced plasma [1], higher harmonic generation [2], and Thomson scattering [3]. XFEL as most promising method is under construction in SPring-8 site [4]. This fourth-generation light source promise the shorter X-ray pulse of several ten fs. Comparing with these complex schemes, simple and compact system which make use of a dipole magnet kicker was proposed by W. Guo [5]. This schemes is based on head-tail oscillation excited after a pulsed kick to the electron bunch with non-zero chromaticity. The vertical beam profile of storage ring is much smaller than that of horizontal one. If we kick the beam in a vertical direction, th tilt is developed enough in 50 turns corresponding to the half period of synchrotron oscillation in a case of the SPring-8. While the pulse width of the X-ray is on the order of 40 ps at SPring-8, the sliced synchrotron radiation with a vertical slit from this beam will become shorter than original X-ray pulse by 1 order for the magnitude to original one in calculation. Because this proposed scheme is accessible for us from beside of not need large scale remodeling of the space where we want to install the kicker, we applied this schemes to SPring-8 storage ring. For our examination of generation of shorter X-ray pulse, we estimate that the needed kick power to induce the enough tilt is about 0.08 mrad as a kick angle at 8 GeV and about 8 mT as a magnetic field using an air core magnet of 0.29 m long. The pulse width is set to 2.6 μs which is shorter than the revolution time 4.7 μs. To realize this kick power, a new kicker magnet system was developed, which can drive the magnet with a current of 200 A. We will report the detail setup of the kicker magnet system and the measurement system of the longitudinal beam profile, then the measured slit sliced optical profile is shown.

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OVERVIEW OF THE EXPERIMENT

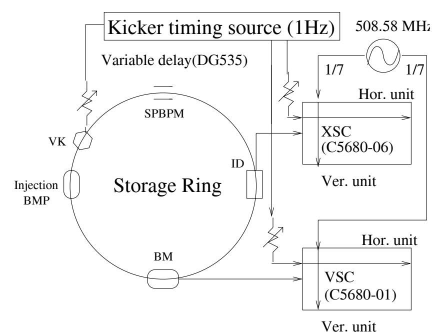

Figure 1: Overview of the experiment system.

Fig. 1 shows the overview of the experimental system. The system consists of a vertical kicker (VK), a driving power supply (PS) system, single pass electron beam position monitor (SPBPM) system, and the streak cameras (SC) to monitor synchrotron radiation. VK system was installed in a place of maximum vertical betatron function (28.8 m) temporarily for this experiment to give a vertical kick to electron beam effectively. The visible and the X-ray streak cameras (VSC and XSC) are installed to a visible light beam line with a bending magnet source and X-ray beam line with an undulator source. Trigger timing signals are distributed to the VK, the SPBPM, and the SC systems simultaneously with the optical fibers by 1 Hz repetitions. Thus, using these trigger signals, the position of the beam center and oscillation of the synchrotron radiation can be observed coincidnt with kick timing. By using synchroscan of the dual scan mode of SC systems and variable delay instruments to the timing signals, we can observe the bunch profile at an any time region after the kick timing.

KICKER AND POWER SUPPLY SYSTEM

We used two 1-turn coil's in parallel to reduce the impedance as small as possible. The coil design is not exactly optimized to output maximum magnetic field in this experiment. The original aluminum chamber of the place where VK is installed was replaced by a ceramic chamber (KYOCERA) of 320(L)$\times$96(W)$\times$38(H) mm whose inner surface is coated by Ti-Mo of about 5 μm thickness to reduce the effect of eddy current. The coil is made of ϕ 2 mm copper wire with 290(L)$\times$45(W) mm to fit the chamber size. The gap of the two coils is 30 mm. The end-point of the coil stands up slightly by about 30 mm to reduce the error field at the end-point. Each coil was fixed on the chamber side like holding the chamber. The search coil (S.C.) was installed to observe the magnetic field waveform. The setup of kicker magnet is shown in Fig. 2 and Fig. 3.

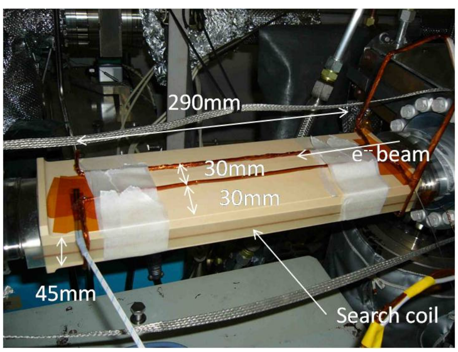

Figure 2: Setup of vertical kicker.

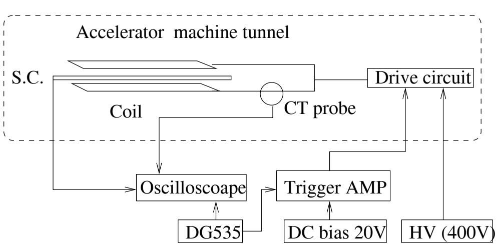

Figure 3: Overview of kicker magnet system.

To realize needed kick power for our experiment, the power supply system was installed close to the coil within 30 cm as much as possible to reduce inductance of the feeder lines. The inductance of the coils and the feeder cables were about 500 nH and 23 μH respectively. The size of made driving circuit was 200(L)$\times$100(W)$\times$50(H) mm. A radiation shield was installed to protect the power supply. The circuit of the power supply is composed of an LC resonant circuit to generate a half sine waveform with the peak current of 200 A and pulse width of 2.6 μs. Fig. 4 shows a schematic drawing of the circuit. The capacitance of the resonant circuit is adjusted to be 0.88 μF to match the pulse width of 2.5 μs. The parallel connected MOSFET's are used to switch the resonant circuit. A low pass filter is inserted to isolate the HV supply from the resonant circuit. An RC snubber circuit is installed to absorb the switching noise. To turn on the MOSFET's, a trigger amplifier is used, which converts the trigger TTL pulse to a 20 V pulse signal. The outputs of the current transfer probe (CT) and S.C. signal shape is shown in Fig. 5. Th horizontal axis was 400 ns/div. The vertical scales for the CT and S.C. were 40 A/div and 500 mV/div respectively. The output signal from the search coil was derivative of the magnetic field. The maximum current was 157 A/coil. The maximum magnetic field was about 5.6 mT.

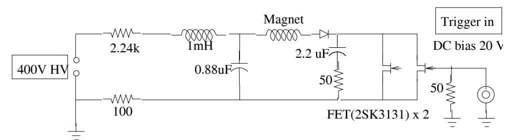

Figure 4: Schematic view of developed drive circuit.

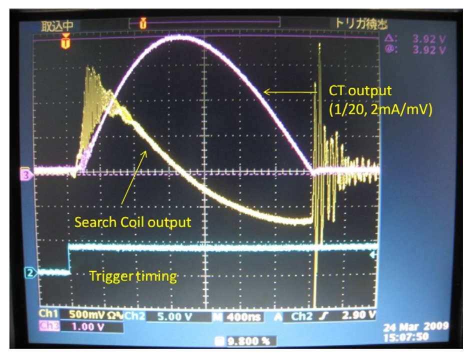

Figure 5: Output signal of S.C. and CT probe in synchronized with trigger timing.

STREAK CAMERA SYSTEMS

We observed the electron beam by two schemes. One is the visible streak camera system, another is X-ray streak camera. The VSC (HAMAMATSU, C5680-01) is installed in the darkened room where the visible light from bending magnet source is steered by mirrors. The visible light is rotated at 90 degrees by mirror and injected to the streak camera. Therefore, we can get the image of the light from side view. The XSC (HAMAMATSU, C5680-06) is put in the radiation shield hutch where X-ray is transported from the undulator source. We use the monochromatic X-ray which was taken out by double crystal monochromator with photon energy of 10.5 KeV whose flux density is maximum on the CsI photo cathode of the XSC. In front of the X-ray streak camera, the Ta slit was put. The horizontal and vertical widths of the slit were ΔX=5.6 μrad ΔY=2.8 μrad respectively. The time resolution and amount of the light is dependent on this slit aperture. For this aperture, in this experiment, we gave preference to increasing flux over getting the short pulse.

RESULTS

The experimental condition is as follows:stored current was single bunch of 1.3 mA, the chromaticity was (ξ_x,ξ_y)=(+1.67,+5.87), betatron tune was (ν_x,ν_y)=(40.1449,18.3506). Monitoring by 14 SPBPMs along the storage ring circumference, the kicker fire timing was adjusted to maximum the coherent oscillation of the single bunch beam. The beam oscillation amplitude was measured by SPBPM, and the kick angle of pulsed magnet was calculated by the known betatron function fitting. From fitting results, we estimated that the given kick angle is 0.0416 mrad and the oscillation amplitude at the source position of the VSC was 1.2 mm in 1st turn. The experiment results of the kicker magnet system are summarized in the table 1. Inconsistency of estimated magnetic field between SPBPM measurements and MAFIA calculation by a factor 2/3 was thought to be caused by a eddy current of the inner coating of chamber.

Table 1: Kicker Performance

Item	Value
Vertical oscillation amplitude	1.2 mm
Estimated kick angle from SPBPM	0.0416 mrad
Estimated magnetic field from SPBPM	3.91 mT
CT probe measurements	156.8 A/coil
	2.6 μs
S.C. output w/o ceramic chamber	5.56$\pm$0.17 mT
Estimated magnetic field from MAFIA and CT	5.71 mT

After the confirmation of the kicker performance, we examined the optical profile by using SC's. We observed an impressive beam tilt about 2.0 mm standard deviation after 50 turns (see upper figure of Fig. 6) by using visible light. However, we could not achieve the shorter visible light after slit slicing because of strong diffraction. The bunch profile after slit slicing was observed with X-ray streak camera as shown in lower Fig. 6. In the case of kicker off, the FWHM result of bunch profile was about 34 ps on average (See left Fig. 6). After a kick, the X-ray disappeared due to the oscillation of the beam center position. On the other hand, in the case of kicker on, the minimum FWHM result of integrated bunch profile was about 7 ps after slit slicing, whose bunch profile is at around 20 μs of horizontal axis in the Fig. 6). We succeeded in producing the shorter X-ray pulse by means of the beam bunch tilt induced with head-tail oscillation, though its value was not sufficient for our requirements.

DISCUSSION

In this experiment, it was difficult to adjust the center of bunch to the center of slit because the center position of beam bunch was shifted turn by turn due to head-tail oscillation. This then shift resulted in turn-by-turn fluctuation of photon flux and difficulty of stable slit slicing of the bunch. Hence, we need to consider not only how to slice the X-ray in stable but also how to increase the duration photon flux at the aimed turn number. The X-ray pulse duration achieved in this study was not as short as we expected. To reduce the width of X-ray pulse, we need to tilt angle of the beam further. We will optimize the X-ray optics including position and width of the slit and also search the optimum chromaticity value corresponding to a given kick angle to tilt the beam effectively and increase the beam current to get a high photon flux. To get enough bunch tilt, we need to increase the current of a coil up to about 300 A/coil. Furthermore, if we use the several-bunch filling mode, to increase the repetition rate of the short X-ray pulses, only one target bunch should be kicked at a time. We are planing to improve the drive circuit to supply larger current of 300 A within 1 μs and with repetitions more than 100 Hz. In addition to this improvement, we are discussing a possibility of giving a reverse kick after about 100 turns in order to reduce the oscillation amplitude during damping time. We will examine new kicker magnet and power supply system near the future based on this experiment.

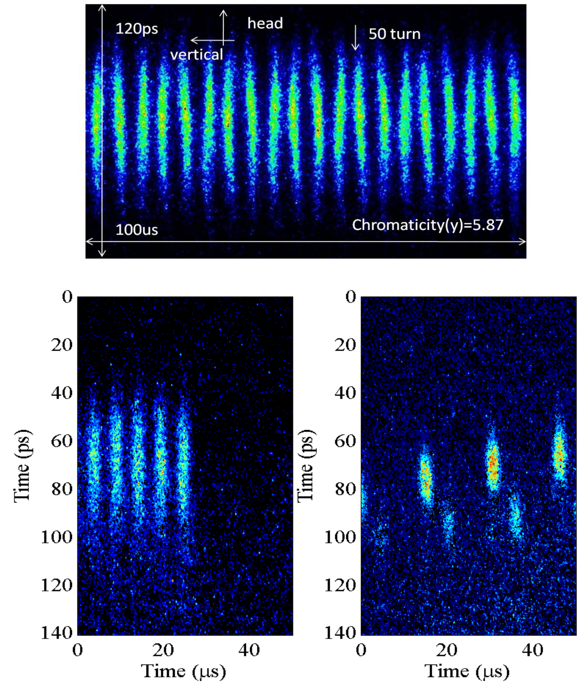

Figure 6: Upper picture shows the profile observed by VSC. Lower figures show the profiles observed by XSC after slit slicing in kicker OFF (left) and kicker ON (right).

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