STATUS AND ACTIVITIES OF THE SPRING-8 DIAGNOSTICS BEAMLINES

S. Takano*, M. Masaki, A. Mochihashi, H. Ohkuma, M. Shoji, and K. Tamura
JASRI/SPring-8, Hyogo 679-5198, Japan
H. Sumitomo, and M. Yoshioka, SPring-8 Service Co. Ltd. (SES), Hyogo 679-5165, Japan

Abstract

At SPring-8 synchrotron radiation (SR) in both the X-ray and the visible bands is exploited in the two diagnostics beamlines. The diagnostics beamline I has a dipole magnet source. Recently, the transfer line of the visible light has been upgraded. A new in-vacuum mirror was installed to increase the acceptance of the visible photons. A new dark room was built and dedicated to the gated photon counting system for bunch purity monitoring. To improve the performance, the input optics of the visible streak camera was replaced by a reflective optics. Study of the power fluctuation of visible SR pulse is in progress to develop a diagnostic method of short bunch length. At the diagnostics beamline I, the size of the electron beam is measured by imaging with the zone plate X-ray optics. The diagnostics beamline II has an insertion device (ID) light source. To monitor stabilities of the ID photon beam, a position monitor for the white X-ray beam based on a CVD diamond screen was installed. A turn-by-turn diagnostics system using the monochromatic X-ray beam of the ID was developed to observe fast phenomena such as beam oscillation at injection for top-up and beam blowups caused by instabilities. Study of temporal resolution of the X-ray streak camera is also in progress at the diagnostics beamline II.

INTRODUCTION

Synchrotron radiation (SR) is a nondestructive probe to diagnose relativistic electron beams in high-energy accelerators. At SPring-8 SR in both the X-ray and the visible bands is exploited in the two diagnostics beamlines [1]. The diagnostics beamline I has a dipole magnet source, and the diagnostics beamline II has an insertion device (ID) light source. In this paper we will report present status and activities of the SPring-8 diagnostics beamlines.

DIAGNOSTICS BEAMLINE I (BL38B2)

The diagnostics beamline I (BL38B2) has a bending magnet light source with critical photon energy of 28.9 keV. In 2011, the transfer line of the visible light was upgraded. The schematic layout of the beamline after the upgrade is shown in Fig. 1. The beamline has an optics hutch and two dark rooms on the experimental hall. The visible synchrotron light is separated from the X-ray beam by two in-vacuum mirrors in the optics hutch. The mirror below the photon beam axis is the original one and the other one above the photon axis has been added in the upgrade. The X-rays pass through the gap of the two mirrors. The separated visible light is transported in a bent shielded pipe out of the optics hutch to the darkrooms. The visible light separated by the lower

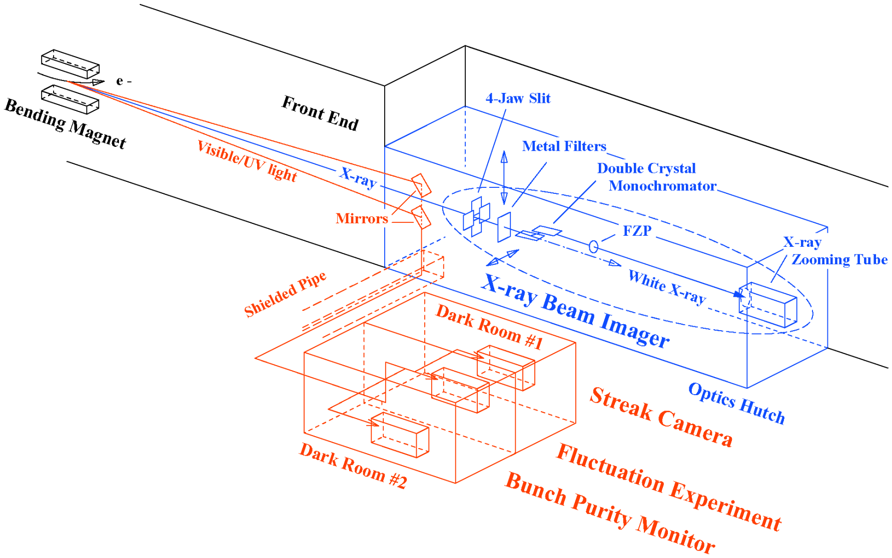

Figure 1: The schematic layout of the SPring-8 diagnostics beamline I (BL38B2).

---

*takano@spring8.or.jp

original mirror is delivered to the second dark room, which has been constructed in the upgrade and dedicated to the bunch purity monitor. The light separated by the upper new mirror is delivered to the first dark room, where the bunch length is measured by streak cameras and studies of incoherent fluctuation of SR pulse are under way. The X-ray line of the beamline is enclosed in the optics hutch. It has a double crystal monochromator that covers the energy range of 4 to 14 keV by (111) reflection of silicon crystals. The X-ray transport line as well as the front end has no windows, which obstructs soft X-ray and visible/UV light and potentially could distort wave front of X-ray SR. Therefore, all the components of the X-ray transport line as well as the monochromator are in bakeable ultra-high vacuum chambers. The X-ray line includes the optical system of the X-ray Beam Imager (XBI), implemented for beam emittance diagnostics.

Streak Cameras

For bunch length measurements, a dual-sweep streak camera (C5680, Hamamatsu) has been operated in the first dark room. In the test studies of generation of short-pulsed SR by kicker magnet, we obtained images of the bunch from the side view with the streak camera and evaluated the tilt of the bunch to optimize the kicker magnet [2]. Turn-by-turn behaviors of the bunch after injection were observed by the streak camera to study longitudinal dynamics of injected beam in the storage ring [3]. In 2011, the input refractive optics of the streak camera was replaced by reflective input optics. The replacement has enabled us to eliminate the narrow bandpass filter and to increase the input photons to the streak camera. The performance of the streak camera for shorter bunch lengths and at lower currents is being studied in low-alpha operation of the storage ring. Recently, a high-resolution steak camera (FESCA-500, Hamamatsu) has been introduced in the first dark room.

Incoherent Fluctuation Experiment

Feasibility study of the so-called fluctuation method for bunch length measuements is in progress in the first dark room. When the radiation pulse with narrow spectral bandwidth Δω has coherence length $(\tau_c \sim 1/\Delta\omega)$ comparable to the source bunch length, its pulse-to-pulse intensity fluctuations have a strong correlation with the bunch length [4]. The required spectral bandwidth to obtain short enough coherence length for sub-ps short bunch is moderate compared to those for longer bunches, making the method advantageous for short bunch length measurement. In the present study, an interferometric filter with a center wavelength of 632.8 nm selected photons within a bandwidth (FWHM) of 1 nm. A silicon avalanche photodiode (APD) module with an effective diameter of 0.5 mm and an embedded amplifier (C5658, Hamamatsu) was used to detect filtered radiation. To reduce the number of transverse coherent modes contributing to the signal fluctuations, the angular acceptance was limited by a 4-jaw slit in front of the focusing lens to the APD. The output signals of the APD were analyzed by a fast digital oscilloscope. Fig. 2 shows an example of a set of intensity histograms for 5000 measurements of a single bunch beam. In the experiment to obtain shorter natural bunch length, the storage ring was operated at a lowered energy of 7 GeV with increased RF voltage of 18 MV. The bunch current was 0.2 mA. The intrinsic fluctuation of power of synchrotron radiation pulse $\Delta I/I$ is calculated by subtracting the fluctuation of the baseline originating from electronic noise. The bunch length deduced by further taking account of contributions of photon shot noise and transverse beam emittance was 11.3 ps (r.m.s.), consistent with that of 10.8 ps measured simultaneously with a visible light streak camera. The observd fluctuation showed a tendency to decrease for longer bunch length obtained by increasing the bunch current. Further experiment of single-shot bunch length measurements is planned by using a single-shot visible light monochromator.

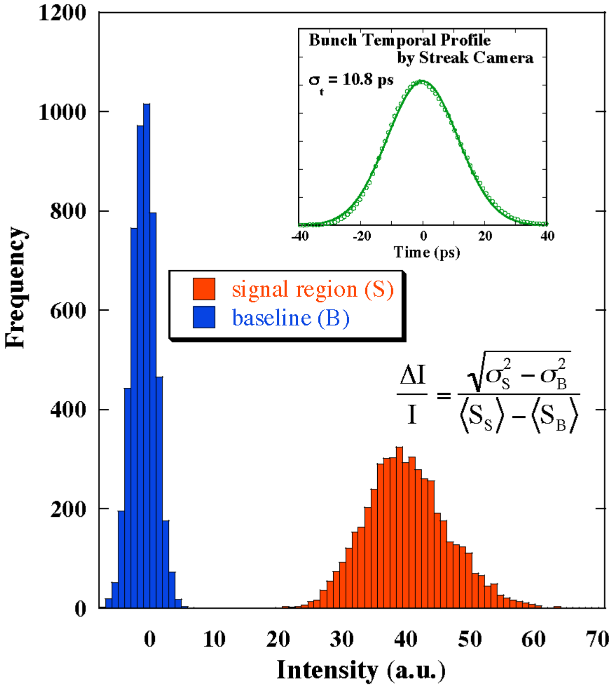

Figure 2: An example of a set of histograms of intensities in the signal region (red) and the baseline (blue) obtained by a oscilloscope (see text). The inset shows a temporal bunch profile measured simultaneously with a visible light streak camera (circles) and a fitted Gaussian curve (line).

Bunch Purity Monitor

The bunch purity monitor in the second dark room is based on the gated photon counting system of visible synchrotron light [5]. It uses a microchannel plate type photo-multiplier tube as a single photon detector. The time spectrum of detected single photons representing the bunch fill pattern is accumulated by a multi channel analyzer (MCA). In order to gate the photons emitted by

ISBN 978-3-95450-119-9

the intense main bunches and to increase the detection efficiency of photons emitted by parasitic satellite bunches a fast light shutter system consisting of two Pockels cells is employed (Fig. 3). The SPring-8 bunch purity monitor can successfully detect parasitic satellite bunches as low as 10^{-9} times the intensity of the main bunches. It is continuously monitoring the purity of isolated main bunches in several-bunch user operation modes under topping-up injection. Upgrade of the bunch purity monitor is in preparation in order to execute immediate measurement of every replenished bunch in topping-up operation. A fast time measurement system for the bunch purity monitor has been developed by employing a time to digital conversion (TDC) VME module (V1290N, CAEN) [6], which will be combined with a hybrid photo detector (HPD) capable of high photon counting rate.

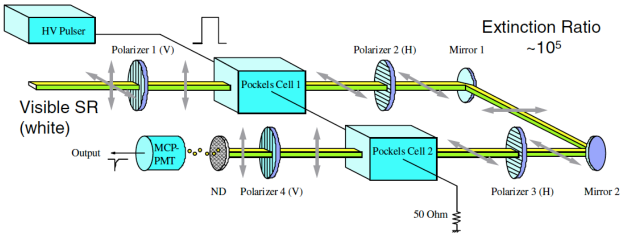

Figure 3: The schematic layout of the bunch purity monitor.

X-ray Beam Imager

For emittance diagnostics of the SPring-8 storage ring, we have implemented the XBI in the optics hutch [7]. The schematic layout of the optical system of the XBI is shown in Fig. 1. The XBI is based on a single Fresnel zone plate (FZP) and an X-ray zooming tube (XZT) (V4410, Hamamatsu). An X-ray image of the electron beam in the bending magnet source of the beamline is obtained by the FZP. To eliminate the effect of the chromatic aberration of the FZP, monochromatic X-rays are selected by the double crystal monochromator. The magnification factor of the FZP is 0.274. To enlarge the reduced X-ray image of the electron beam the XZT is employed as an X-ray camera. The combined magnification of the XBI is 13.7 when the magnification of the XZT is set at 50. The observing photon energy of the XBI is 8.2 keV, which was determined by considering the spatial resolution and the efficiencies of the FZP and the XZT. The spatial and time resolution of the XBI are 4.1 μm (1σ), and 1 ms, respectively.

To further increase the brightness of SPring-8, persistent efforts towards reduction of the beam emittance have been made. Recently, extensive study of optimization of storage ring optics is in progress to reduce the natural emittance of nominal 3.4 nm.rad to 2.4 nm.rad [8]. We have measured the beam size with the XBI in the study and have confirmed that the emittance is successfully controlled.

DIAGNOSTICS BEAMLINE II (BL05SS)

The diagnostics beamline II (BL05SS) has an ID as the light source. The edge magnetic fields of the two bending magnets at the both ends of the ID straight section are also available as the light sources. The out-vacuum type ID is mounted on a girder which can be slid on guiding rails embedded in the floor. The sliding mechanism of the ID enables us to remove it off the electron beam axis and to change its permanent magnets in the accelerator tunnel. The magnet array of the ID is presently of Halbach type with 51 periods of 76 mm long. The maximum value of the deflection parameter K is 5.8 [9]. The layout of the diagnostics beamline II is shown in Fig. 4. It has two optics hutches and one experimental hutch. The X-slit and the Y-slit in the front end are employed to shape the white X-ray beam of the ID. The optics hutch I has the adjustable graphite and metal filters with moving mechanisms, which are employed to fit the intensity and the spectrum of white X-ray beam for beam diagnostics purposes and SR irradiation experiments planned to develop accelerator components such as photon absorbers [1]. The optics hutch II has a cryogenic double crystal monochromator that covers the energy range of 4 to 38 keV by (111) reflection of silicon crystals. The transport line of the monochromatic X-ray beam shielded by lead connects the optics hutch II and the experimental hutch. In 2011, we installed a position monitor for the white X-ray beam in the optics hutch I to monitor stabilities of the ID photon beam. A turn-by-turn diagnostics system based on a fast fluorescence screen was developed in the experimental hutch, to observe fast phenomena such as

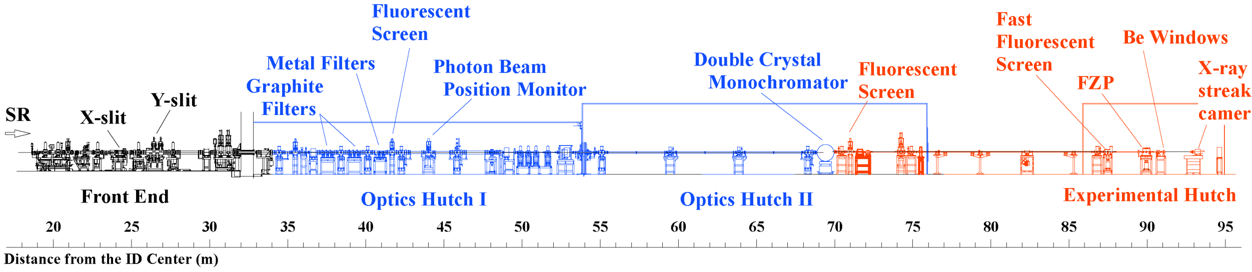

Figure 4: The SPring-8 diagnostics beamline II (BL05SS).

beam oscillation at injection for top-up and beam blowups caused by instabilities. The experimental hutch has beryllium exit windows for monochromatic X-ray. Precise measurement of the flux density of the ID X-ray beam and study of temporal resolution of the X-ray streak camera are also in progress in the experimental hutch.

Photon Beam Position Monitor

In 2011 we installed in the optics hutch I a position monitor for the white X-ray beam to watch the stability of the photon beam axis of the ID. Stability of the photon beams of the IDs is one of the most important issues to be achieved at SPring-8. In 2006, the signal processing electronics of the beam position monitors (BPMs) included in the periodic orbit correction loop were replaced by new one that have the resolution as small as 0.1 μm [10]. Recently, to further stabilize the photon beams against perturbations to the electron beam orbit caused by changes of magnet gaps of the IDs and by operations of ID elements for switching of polarizations of output photons, the cycle time of the orbit correction loop has been reduced from the former seven seconds to one second.

The photon beam position monitor employs a thin CVD diamond screen, which visualizes the X-ray beam. Though the screen is destructive to the photon beam, it enables us to observe directly the peak of the white ID beam and to measure precisely the position of the beam, rendering the monitor a promising tool to watch the stability of the ID photon beam axis. The setup of the photon beam position monitor is shown in Fig.5. The screen is mounted on a copper holder, which is water-cooled. The thickness of the CVD diamond screen is 50 μm. The holder of the screen is actuated by an air cylinder, which has two operating positions for 1) beam observation and 2) retraction for other activities of the beamline. The screen is set at an angle of 45° with respect to beam direction and the beam profile on the screen is observed by a precision CCD camera. The camera is a high resolution (2448 x 2050) gigabit ethernet camera (piA2400-17gm, Basler), which is connected to the control network of SPring-8. The camera is controlled by a dedicated personal computer on the network. We developed a control software of the camera, which periodically captures the image of the photon beam, analyzes the image of the beam spot on the screen, and stores the analyzed position of the beam to the database of the SPring-8 control system.

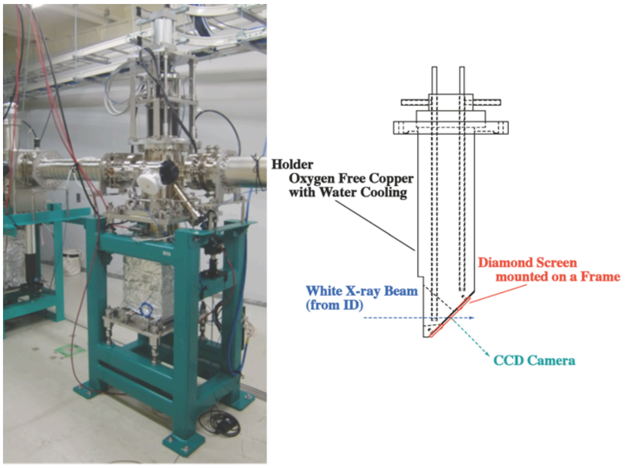

Figure 5: Photon Beam Position Monitor.

In 2012, we started continuous measurement of the photon beam position except for the periods when other activities occupy the beamline II and are evaluating the performance of the monitor.

X-ray Flux Measurement

Recently, at SPring-8 extensive study of optimization of storage ring optics is in progress to reduce the natural emittance of nominal 3.4 nm.rad to 2.4 nm.rad [8]. To verify the benefit of emittance reduction to the photon flux of IDs as theoretically predicted, we measured the flux density of 10 keV photons from the ID of the diagnostics beamline II. We put an ion chamber near the beryllium exit window in the experimental hutch. We set an angular aperture at 4 μrad x 4 μrad by putting a 4-jaw slit in front of the ion chamber. We measured the spectral flux density by changing the output energy of the monochromator in the optics hutch II. The magnet gap of the ID was fixed so that the energy of the third harmonic radiation is 10 keV. The measured flux density of the new 2.4 nm.rad optics was 1.3 times higher than that of the present (Fig. 6), and it is consistent with theoretical calculation by SPECTRA [11].

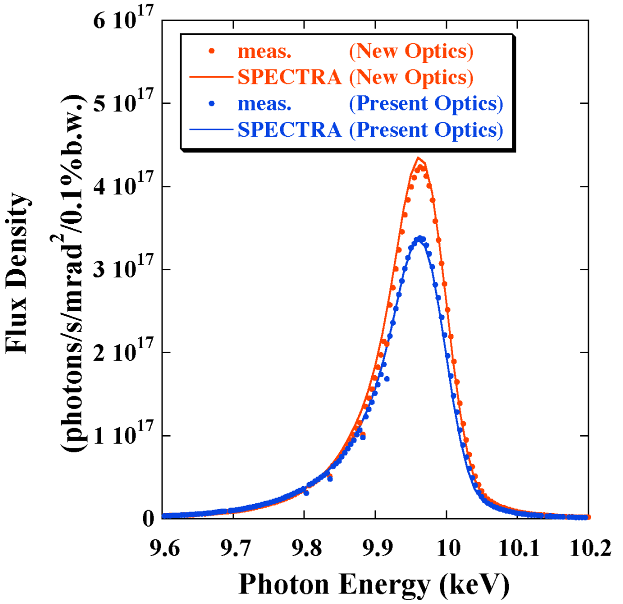

Figure 6: Flux density of 10 keV X-ray of the ID of the diagnostics beamline II for the present optics (blue) and the new low-emittance optics (red). The measured results (circles) are in good agreement with theoretical calculation by SPECTRA (lines).

Turn-by-turn Beam Diagnostic System

In the experimental hutch, we have developed a turn-by-turn beam diagnostic system by observing spatial profile of the monochromatic X-ray radiation of the ID. It has a fast fluorescence screen (YAG:Ce) with decay time of several tens of nanoseconds in a vacuum chamber of the beamline, which converts the X-ray beam profile into a visible light image. The two-dimensional visible image on the screen is further transformed into two line images corresponding to the horizontal and the vertical profile, respectively, by an optical system implemented on a optical table in the atmosphere. A fast-gated CCD camera with an image intensifier simultaneously captures the two line images. With this system studies of the stability of the storage ring beam are in progress, such as oscillations of the stored beam excited by injection bumps for topping-up, and variations of beam size and energy spread in instabilities of a high current single bunch beam. The details of the experimental setup of the system as well as its working principles, and results of beam observations will be presented in a separate paper [12].

X-ray Streak Camera

We installed an X-ray streak camera (C5680-06, Hamamatsu) in the experimental hutch. In the test studies of generating short X-ray pulse with a vertical kicker at SPring-8, we measured with the X-ray streak camera the length of X-ray pulse sliced by a narrow horizontal slit and successfully demonstrated the reduction of the pulse length [2]. One of the key technical issues of the experiment is the temporal resolution of the X-ray streak camera, which is dominated by effects of velocity spread of the secondary electrons from the photocathode that converts the X-ray photons into the electrons. To evaluate the effects on the temporal resolution quantitatively, we have studied temporal spread of single X-ray photons as measured by the X-ray streak camera. Detailed results of the single photon experiment will be given in a separate paper [13].

We installed an FZP in the experimental hutch to focus the photon beam on the input photocathode of the X-ray streak camera for single-shot measurements of faint bunches such as injected beams. Tuning of the FZP and the X-ray streak camera for single-shot measurements is under way.

REFERENCES

[1] S. Takano et al., “Overview of the SPring-8 Diagnostics Beamlines,” SRI2009, Melbourne, September – October 2009, AIP Conf. Proc. 1234 (2010) p.399.

[2] C. Mitsuda et al., “Current Status of Short X-ray Pulse Generation with a Vertical Kicker in the SPring-8 Storage Ring,” WE-D-P-28 , to appear in the proceedings of SRI2012, Lyon, July 2012.

[3] T. Watanabe et al., “Measurement of Longitudinal Dynamics of Injected Beam in a Storage Ring,” IPAC2011, San Sebastián, September 2011, THPC031, p. 2978 (2011); http://www.JACoW.org

[4] M. S. Zolotorev and G. V. Stupakov, SLAC-PUB-7132, March 1996.

[5] K. Tamura and T. Aoki, “Single Bunch Purity during SPring-8 Storage Ring Top-Up Operation,“ Proc. 1st Annual Meeting of Particle Accelerator Society of Japan 2004 (2004) p.581;http://www.pasj.jp/web_publish/pasj1_lam29/WebPublish/5P50.pdf

[6] A. Kiyomichi et al., “Upgrade of Time Measurement System for Bunch Purity Monitor at SPring-8,” WEPS106, to appear in Proc. 9th Annual Meeting of Particle Accelerator Society of Japan, Toyonaka, August 2012 (in Japanese).

[7] S. Takano, et al., Nucl. Instr. and Meth. A556 (2006) p.357.

[8] Y. Shimosaki et al., “Optimization of Lower Emittance Optics for the SPring-8 Storage Ring,” TUPPC013 , to appear in the proceedings of IPAC2012, New Orleans, May 2012.

[9] M. Masaki et al., “Characterizations and Applications of the Insertion Device of the SPring-8 Diagnostics Beamline II,” SRI2009, Melbourne, September – October 2009, AIP Conf. Proc. 1234 (2010) p.560.

[10] T. Fujita et al., “Commissioning and Status of New BPM Electronics for COD Measurement at the SPring-8 Storage Ring,” PAC2007, New Mexico, June 2007, FRPMN031, p.3997 (2007); http://www.JACoW.org

[11] T. Tanaka and H. Kitamura, SPECRA code ver. 9.02 (2012); http://radiant.harima.riken.go.jp/spectra/index.html

[12] M. Masaki et al., “Development of Turn-by-turn Beam Diagnostic System using Undulator Radiation,” TUPB63 , these proceedings.

[13] A. Mochihashi et al., “Measurement of Temporal Resolution and Detection Efficiency of X-ray Streak Camera by Single Photon Images” MOPA48 , these proceedings.