DEVELOPMENT AND CONSTRUCTION STATUS OF THE BEAM DIAGNOSTIC SYSTEM FOR XFEL/SPRING-8

S. Matsubara#, H. Ego, K. Yanagida, T. Togashi, and H. Tomizawa,
JASRI/SPring-8, 1-1-1, Kouto, Sayo, Hyogo, 679-5198, Japan
H. Maesaka, S. Inoue, T. Ohshima, K. Tamasaku, K. Togawa, H. Tanaka, A. Higashiya, M. Yabashi, T. Shintake and Y. Otake, RIKEN/SPring-8, 1-1-1, Kouto, Sayo, Hyogo, 679-5148, Japan

Abstract

We report the design, performance, and installation of the beam diagnostic system of XFEL/SPring-8. The electron beam bunches of the XFEL accelerator are compressed from 1 ns to 30 fs by bunch compressors without emittance growth and the peak-current fluctuation of the accelerator directly causes SASE fluctuation. To maintain stable bunch compression process, the accelerator requires rf cavity beam-position monitors (BPM) with 100 nm resolution, OTR screen monitors (SCM) with a few micro-meter resolution, fast beam current monitors (CT), and temporal structure measurement systems with resolution of under a picosecond. The performance of each instrument was tested at the SCSS test accelerator and was found to be sufficient for our requirement. To measure the temporal structure of the electron bunch, three types of measurement systems a streak camera, an EO sampling measurement, and a transverse deflecting cavity with a resolution of few-tens femtoseconds have been prepared. The streak camera and EO sampling show sub-picosecond resolution. The installation of these beam diagnostic systems to the XFEL accelerator is well under way.

INTRODUCTION

An x-ray free electron laser facility at SPring-8 (XFEL/SPring-8) [1] is under construction to advance the frontiers of life sciences, material sciences, etc. by means of coherent and extremely intense x-rays. The XFEL employs the SCSS concept [2, 3] which was evidenced in the SCSS test accelerator [3]. The XFEL consists of an electron injector with a low-emittance thermionic gun, C-band high-gradient accelerators and short-period in-vacuum undulators. The XFEL light is generated by a self-amplified spontaneous emission (SASE) process. The target wavelength is less than 0.1 nm, which comes from a beam energy of 8 GeV. To achieve a stable SASE process, the electron beam is required to have low-slice emittance of less than 1 π mm mrad and high-peak current of more than 3 kA.

In the mean time, the bunch length is shortened from 1 ns to 30 fs by using the velocity bunching process of multi-sub-harmonic acceleration cavities and the bunch compression process of three magnetic chicanes. Finally, the peak current becomes 3 kA without emittance growth.

Table 1: Summary of the number of the beam monitors for the XFEL

Monitor kind	Number
rf cavity BPM	56
Screen Monitor	43
Current Transformer	30
Transverse Deflecting Cavity	1
Streak Camera for OTR	3
EO Sampling	1

The electron beam is fed into in-vacuum undulators to overlap with an emitted x-ray along an undulator section with about 70 m in net length, and then XFEL light is produced.

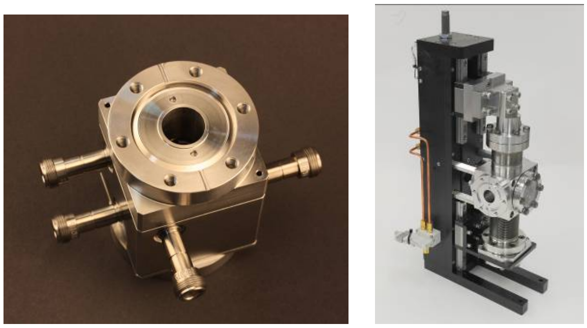
To control such high-precision beam characteristics, various measurement systems [4, 5] are need to monitor the transverse beam profile, the temporal bunch structure, the beam position, the beam charge and the beam arrival timing at each stage. In order to fulfill these demands, we have prepared an rf cavity beam position monitor (RF-BPM), a precise screen monitor (SCM), a high-speed differential current transformer (CT), temporal structure measurements using a transverse rf deflecting cavity system, a streak camera system, and an EO sampling system. The number of monitors for each device is summarized in Table 1. So far, monitor devices have already been installed to in the accelerator tunnel of the XFEL. A detailed description of each monitor is given in the next section.

DESIGN OF THE MULTI-STRIPLINE BPMSTATUS AND PERFORMANCE OF EACH DIAGNOSTIC DEVICE

RF Cavity BPM [6]

The configuration of the RF-BPM is shown Fig. 1 (a). The RF-BPM was designed to use a TM110 dipole resonance field excited in a cylindrical cavity by an electron beam. Besides, the RF-BPM has an additional TM010 monopole cavity to determine the beam charge and the phase reference of beam arrival. These two cavities of the RF-BPM have the same resonant frequency

#matsubara@spring8.or.jp



(a) RF-BPM (b) SCM chamber

Figure 1: Configuration of the RF-BPM cavity and the SCM chamber.

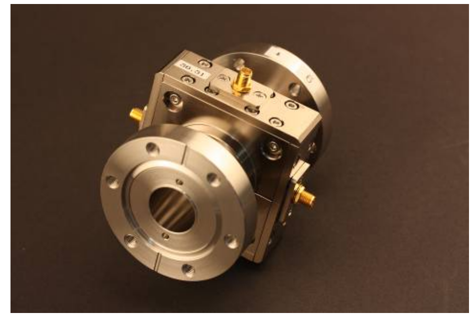


Figure 2: Configuration of the differential CT.

of 4760 MHz. The rf signal from the RF-BPM is processed by a detection circuit with In-phase and Quadrature demodulator, and is then recorded by a 16 bits VME A/D converter board driven by a 238 MHz clock. The position resolution was 0.2 μm. The RF-BPM system with this measurement accuracy satisfies our XFEL demand.

Screen Monitor [4, 5]

To obtain the transverse beam profile, screen monitors (SCM) are employed. The configuration of the SCM is shown in Fig.1 (b). The SCM uses two kinds of screens: one is a fluorescent screen of Ce:YAG for a low-energy beam, and the other is an optical transition radiation (OTR) screen using a stainless steel foil with 0.1 mm thick for a high-energy beam. In order to achieve a resolution of a few-μm, an original imaging system was developed with a custom-made lens system and a motorized zoom mechanism changing from1x to 4x. The transverse beam profile on the screen is transported through the imaging system on a CCD camera. The SCM systems measured appropriately the electron beam with about 10 μm size using both a Ce:YAG and a stainless steel foil. The screen is moved by a pneumatic actuator in the chamber.

Current Transformer [5]

High-speed differential current transformers (CT) have been developed for the XFEL. Some of the main purposes of the CT are measurement of the beam charge to monitor appropriate beam transport, and detection the beam arrival timing so as to adjust the activation timing of an accelerator component. Moreover, it is possible to confirm the bunch length with sub-ns at the injector part of the XFEL. Figure 2 shows a schematic view of the CT. The CT has four outputs: two pairs of positive and negative signals in order to obtain differential signals. By subtracting the negative signal from the positive one, common-mode noise, such as noise from a klystron power source, is eliminated.

This differential CT was evaluated by using an electron beam at the SCSS test accelerator. The differential CT was able to reduce the common-noise to 1/10. The rise time of the signal was 200 ps through the electron beam with about a 300 fs bunch length. The rise time is faster than the electron bunch length from 1 ns to 500 ps at the electron gun and the 238 MHz sub-harmonic buncher. The signal peak of the high-speed differential CT was linear to the electron beam charge.

Status of Installation for the XFEL

Three kinds of measurement systems have been made and installed in the accelerator part of the XFEL. The installed numbers are 27 for the RF-BPM, 23 for the SCM vacuum chamber, and 15 for the CT. The RF-BPMs were aligned with the magnetic center of the quadrupole magnet with accuracy of 40 μm. For the SCM, hereafter the imaging systems are going to be installed and adjusted with their pedestals. Remaining installation will be done presently.

EVALUATING OF BUNCH LENGTH MEASUREMENT SYSTEMS [7]

To measure the electron beam bunch length, three measurement systems, which are a streak camera, a transverse rf deflector, and an EO sampling method, have been prepared. A C-band transverse rf deflector cavity was newly designed. This cavity is a periodical disk-loaded accelerating guide with race-track shape irises, named RAIDEN [8]. It is under construction. The streak camera and the EO sampling method were evaluated reciprocally.

The electron beam has to be measured by these various systems for each bunch length with a wide range of around four orders of magnitude in the XFEL. The streak camera, EO sampling, and a classical rf zero-phase crossing method [9] cover a time range of several hundred femtoseconds. These methods were made sure of these accuracy and the consistency by measuring the same electron bunch of the SCSS test accelerator [7].

For the streak camera method, a streak camera (FESCA200), an OTR screen and an optical propagating system for the OTR light were employed. To achieve a high measurement resolution, the wavelength width of the OTR light was restricted from 640 nm to about 850 nm,

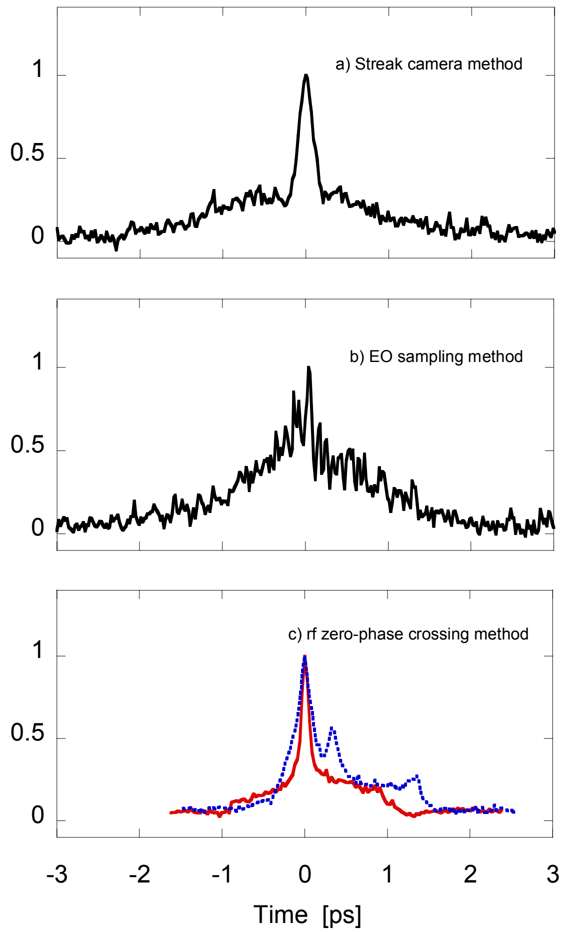


Figure 3: Measured bunch length from the streak camera, rf zero-phase crossing, and EO sampling method.

since the broad spectrum causes an optical group delay in the optical pass and energy dispersion on the photoelectric surface in the streak camera.

As a non-destructive measurement system, the EO sampling system has a probe laser pulse, an optical polarization controller, and an EO crystal of ZnTe. When an electron beam passes through near to the EO crystal, the probe laser is affected by a birefringence effect induced from the electron beam. The probe laser pulse after passing through the EO crystal has the configuration of an electron bench in the temporal region.

Figure 3 shows the results of electron bunch length measurements by three methods. The measured bunch lengths were about 300 fs (FWHM) with a pedestal of about 1 ps. The 300 fs bunch lengths correspond to the spiky electron bunch concerned with the lasing while ID sections. These three methods gave the same value for the electron bunch length.

SUMMARY

Various monitor systems of the XFEL have been prepared for the transverse beam profile, temporal bunch structure, beam position, beam charge, and beam arrival timing. These monitors are RF-BPM systems with a position resolution of less than 0.2 μm, SCMs with a size resolution of sub-10 μm, CTs with a 0.2 ns rise time and low-noise. The temporal measurement system using the C-band RAIDEN cavity for a bunch length under 100 fs is under production. The bunch length measurement systems using the streak camera and the EO sampling method have already been developed for observing under 1 ps. The temporal accuracy of the measurement systems using the streak camera and the EO sampling were reciprocally evaluated with measured bunch lengths of 300 fs, respectively.

The monitors, as mentioned above, have almost installed been in the accelerator part of the XFEL. The remaining monitors, which are under development or production, will be installed along the undulator part. The installation of these beam diagnostic systems is proceeding smoothly.

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