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BEAM STUDIES IN DIAGNOSTIC BEAMLINE AT PLS*

J. Y. Huang[#], D. K. Seon, I. S. Ko, and T. -Y. Lee
Pohang Accelerator Laboratory, Pohang 790-784, Korea

Abstract

A diagnostic beamline has been operated in the PLS storage ring for the diagnostics of electron- and photon-beam properties. It consists of two optical imaging systems: a visible light imaging system and a soft x-ray imaging system. We measure transverse and longitudinal beam structure with a streak camera to study short-time beam dynamics from the visible light image. Accurate transverse beam size is measured with soft x-ray image to minimize diffraction error. In this paper, results of the beam studies and the measurement of beam parameters are summarized and discussed.

1 INTRODUCTION

The Pohang Light Source (PLS) is a third generation synchrotron light source dedicated to many scientific applications. The storage ring is equipped with various electron- and photon-beam diagnostic instruments such as the beam position monitor, beam current monitor, photon beam monitor, and the beam feedback system to stabilize photon beam. Photon beam diagnostics is an essential technique for the study of the small-scale electron beam structure as well as its temporal dynamics in short-time scale [1, 2]. For this purpose, a diagnostic beamline has been operated in PLS for the measurement of the transverse electron beam shape, beam position and the longitudinal structure of the bunch from the synchrotron radiation source.

Various machine parameters were measured in the diagnostic beamline with imaging systems at two different band of wavelengths: visible light and soft x-ray. Transverse beam position is monitored with a position-sensitive photodiode detector, and the beam-size is measured with a 2-dimensional CCD camera or with two linear photodiode-arrays. Time-averaged bunch length is measured with a fast photodiode in conjunction with a fast sampling oscilloscope. A synchroscan streak camera is used for the study of the transient beam structure with 2 ps resolution. On the other hand, more precise beam size is measured with x-ray optics.

In this paper we describe the status of the PLS diagnostic beamline, and various beam diagnostics and result of beam studies being conducted using synchrotron radiation.

2 DIAGNOSTIC BEAMLINE

The diagnostic beamline extracts the source light from the bending magnet located at the center of the triple-bend arc sector. From the bending magnet radiation, 8 mrad is used for the visible light imaging system and 2 mrad is used for the x-ray imaging system. Designed beam size at the sector symmetry point is σ_x =185 μm, and σ_y =59 μm, and the design value of the emittance is 12.1 nm-rad. The source point is 2.9° behind the symmetry point of the bending magnet where the beam size and the divergence is slightly different from the center of the magnet. Since the visible light image has large diffraction error ($R_y = (\rho\lambda^2)^{1/3}$ where ρ is bending radius and λ is wavelength) in the low emittance source due to the very small radiation angle [2], an x-ray imaging system is used for the precise measurement of the spatial beam structure with the minimum diffraction error. Diffraction error of the imaging system with 440 nm (2.8 eV) visible light is around 100 μm vertically, but is less than 10 μm with 284 eV soft x-ray. The visible light imaging system is mainly used for study of the temporal beam structure and transient beam dynamics in the picosecond regime. A layout of the diagnostic beamline is shown in Fig. 1 and more description on the beamline refers to Ref. [3].

2.1 Visible Light Optics

The visible light imaging optics consists of a water-cooled copper mirror inside the vacuum tank, a remote controlled beam-steering mirror outside the vacuum and two achromatic lenses. An 1:1 image is formed by two achromatic lenses of 3 m focal length, and is delivered onto the optical table mounted with various detectors inside a dark room. Two imaging lenses are located with a mirror-symmetry. The first focusing lens is located at 7.5 m from the source point and the second mirror is located at 7.5 m from the final image point. Total distance from the source to the image is 25 m.

2.2 X-ray Optics

The x-ray imaging system consists of a flat deflecting mirror, two spherical mirrors arranged as a Kirkpatric-Baez optics [4] for horizontal and vertical focusing, and a 5 μm carbon foil to cut off the low energy photons. Vertical and horizontal focusing mirrors are located at 10.581 m and 10.911 m from the source point and the image is formed at 21.492 m from the source.

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[#] Email: huang@postech.ac.kr.

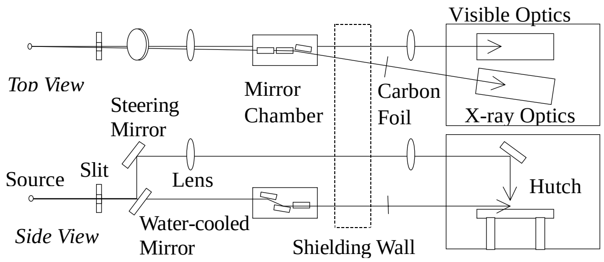

Fig. 1 Layout of the diagnostic beamline.

All three mirrors have 3° grazing incidence angle. A flat water-cooled mirror is made of nickel-plated Glidcop, and two spherical mirrors are made of single-crystalline Silicon. All the mirrors are coated with 250 nm thick nickel. The high energy photon above 0.8 keV is absorbed by the grazing incidence metal mirrors and the low energy photon below 200 eV is absorbed by the carbon foil. Since the carbon foil has the sharp absorption edge at 284 eV, the combination of all beamline components passes only 200 eV to 284 eV photons, forming a band-pass filter.

Ray tracing of the x-ray imaging optics has been performed with SHADOW program. Starting from the source point located 2.9° behind the center of the bend-magnet, including various conditions of the optical component errors, the ray tracing has shown the distortion or aberration errorof the optics is acceptable to within the specification. Wave-front distortion or the image diffuse error by the carbon foil and the scintillation plate are not considered.

2.3 Detection Instruments

Transverse beam parameters are measured with the photo-diode detectors: two 25μm x 512 linear photodiode array, a CCD camera with 9.7μm x 9.7μm pixels and a position-sensitive photodiode. We use a fast 20GHz optical-to-electrical (O/E) converter (New Focus 1437) plugged into a 20GHz sampling-oscilloscope (TEK CSA803A) for the measurement of the bunch length. Both components have 17ps input rise-time. The optical image is guided to the O/E input through a 4 μm single mode optical fiber. Two 15 dB, 25 GHz amplifiers are used for the amplification of the O/E output signal.

To measure the transient bunch structure in time domain, a Hamamatsu streak camera(C5680) is installed on the optical table in the experimental hutch. Not only the picosecond-regime bunch-structure measurement in the time domain with fast-scan module but also the spatio-temporal measurement of the bunch train is possible with a slowscan and a synchroscan module.

Two kinds of beam position monitors are used in the diagnostic beamline. An x-ray position monitor made of two gold plated electrodes measures the vertical beam position with vertical sensitivity of 0.4%/μm at the center of the monitor. A quadrant photodiode sensor measures beam positions with 0.1%/μm sensitivity using the visible light image.

3 BEAM MEASUREMENTS

In the diagnostic beamline, various beam parameters have been measured such as transverse beam size, beam emittance, and bunch length. The 'fast beam ion instability' [6] has been observed at the diagnostic beamline by increasing the residual gas pressure in the storage ring.

3.1 Beam Size and Emittance

We measure beam sizes from visible images as well as from x-ray images. True beam size is estimated from the measured value by subtracting the diffraction-limit error. The horizontal beam size σ_x is 303 μm and the vertical beam size σ_y is 63 μm when measured with a visible light image. The beam emittance obtained from this measurement is 40 nm-rad, which shows large difference compared to the design value of 12.1 nm-rad. Since it is an integrated beam image during the CCD exposure time around 100 ms, the measured beam size contains beam oscillation amplitudes induced by beam instabilities. The beam instability is mainly due to the higher order modes of the rf cavity. When the rf cavity temperature is adjusted carefully to an optimum condition to suppress the higher order cavity modes, the beam size is reduced to 182 μm and the equivalent emittance is 11.3 nm-rad. Vertical beam size is still larger than the expected value, ~40μm obtained from the coupling-ratio measurement [5]. In both cases, we have used the design values of the dispersion function and beta function to get the beam emittance.

In x-ray optics, an image is formed on a thin fluorescent crystal and we measure the beam size with negligible diffraction error. This image is monitored with a CCD camera through a micro-telescope. With 5μm carbon filter, we have obtained 43μm for vertical beam size and 186μm for horizontal beam size at 100mA. It gives 12nm-rad of beam emittance, implying that the storage ring has reached its design performance. Measured beam parameters are summarized in Table 1.

Table 1: Measured and designed beam parameters.

Beam parameters	Measured value	Design value
σ_x	182μm	189μm
σ_y	40μm	59μm
σ_s	21ps	17ps
ε_x	11.3 nm-rad	12.1nm-rad

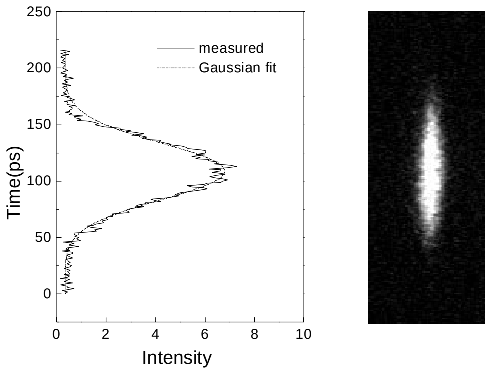

Fig.2 Bunch length measurement by Gaussian fitting of the profile from the streak camera image.

The x-ray imaging system has shown an unexpected intensity-dependence in the measurement of beam sizes. When we use 10μm carbon filter, beam size decreases to 33μm. Further investigation and refinement of the x-ray optics are planned for more precise measurement.

3.2 Bunch Length

Bunch lengths are measured by a fast sampling oscilloscope and a streak camera. Using a sampling oscilloscope, the synchrotron oscillation amplitude adds up to the signal. By subtracting the instrumental rise-time effect from the measured value, the true bunch length is 33 ps which is also very long compared to the design value of 17 ps due to the longitudinal beam instability. Using a streak camera, we have measured true single bunch lengths as shown in Fig. 2 and 3. Figure 3 shows the bunch length vs beam current. The estimated value with SPEAR-scaling is also drawn on the measured data for comparison. It shows reasonable agreement with calculated values but the onset of the instability starts at higher bunch current than expected. For the case of 0.1mA, 0.2mA, and 0.5mA, multibunch-length is used for the single bunch lengths at lower bunch current.

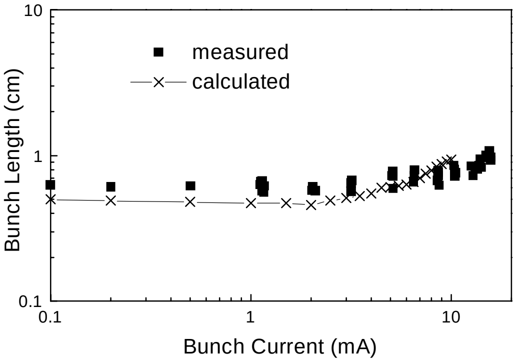

Fig.3 Bunch current vs bunch length.

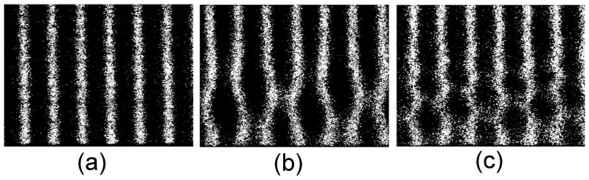

Fig.4 A fast-beam-ion-instability signal taken with streak camera: a) normal state, b) when ion pumps are turned off, bunch-train tail oscillates at CO-ion frequency, c) ion frequency increases with He injection. x: 25μs, y: 500ns.

3.3 Fast Beam-Ion Instability

The fast beam-ion instability (FBII) has been directly observed from the storage ring by injecting Helium gas to increase the growth time. Snapshots of the bunch train were taken by a streak camera and a single-pass beam position monitor. By measuring the amplitude of the beam oscillation, ion frequency, and the vertical bunch size along the bunch train, we have observed characteristic signals of the FBII: increase of the oscillation amplitude and the bunch size along the bunch train with expected beam-ion oscillation frequency. A beautiful visual evidence of the fast beam-ion instability is shown in Fig. 4 [7].

4 SUMMARY

A visible optics is under normal operation in PLS for the transverse and longitudinal beam profile measurements. Various instruments such as a CCD camera, photodiode arrays, position sensitive photodiodes, a synchroscan streak camera and a fast photodiode detector are equipped at the focal plane of visible optics. We could measure the transverse beam profiles, beam position and the longitudinal bunch structure in micrometer spatial-scale and the picosecond temporal-scale. In particular, we study the spatio-temporal beam properties of the electron beam with a streak camera. An x-ray image is used for the precise beam size measurement with a negligible diffraction error. However, the x-ray imaging system has shown an unexpected intensity-dependence in the measurement of beam sizes. Further refinement of the x-ray optics is planned for the precise measurement of the beam size and the beam emittance.

5 REFERENCES

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