A BEAM PROFILE MONITOR BASED ON AN X-RAY ZONE PLATE OF THE SPRING-8 STORAGE RING

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Abstract

A beam profile monitor based on an X-ray zone plate has been installed in the accelerator diagnostics beamline I (BL38B2) of the SPring-8 storage ring. A single phase zone plate and an X-ray zooming tube are used to image the synchrotron radiation from a dipole magnet source. Monochromatic X-ray is selected by a double crystal monochromator. The zone plate is focused by changing the output photon energy of the double crystal monochromator. Focused images of the electron beam have been successfully obtained. Based on preliminary calibrations of the X-ray zooming tube, the horizontal and vertical beam sizes (1σ) are roughly estimated to be 120 μm and 15 μm, respectively.

INTRODUCTION

Measurement of small vertical size of electron beam is among the most important emittance diagnostics of low emittance synchrotron radiation sources. In the case of the SPring-8 storage ring, because of the high energy of electrons, 8 GeV, and the large bending radius of 39.3m, visible synchrotron radiation from a bending magnet is narrowly collimated in the vertical direction, and diffraction effect severely limits the resolution of conventional electron beam imaging with visible light.

Interferometry is an alternative method to overcome the diffraction-limited resolution. We have developed a two-dimensional visible synchrotron light interferometer, which enables us to obtain two-dimensional information on transverse profile of an electron beam with twice better resolution than imaging systems[1]. However, the narrow aperture of the vacuum duct transporting visible synchrotron light limits the spatial resolution of the SPring-8 interferometer to about 50 μm in the vertical direction, which is apparently larger than the vertical beam size evaluated by other methods[1].

Improvement of the diffraction-limited resolution by orders of magnitude can be achieved by utilizing synchrotron radiation in shorter wavelength regions such as X-rays[2]. To measure the size of the electron beam of the SPring-8 storage ring by observing X-ray synchrotron radiation, we have constructed the accelerator diagnostics beamline I (BL38B2), and have installed a beam profile monitor based on an X-ray zone plate.

ACCELERATOR DIAGNOSTICS BEAMLINE I (BL38B2)

The accelerator diagnostics beamline I (BL38B2) of the SPring-8 storage ring has a bending magnet light source, and wide band spectral availability including visible/UV light, and soft and hard X-rays has been achieved. The beamline consists of a front end in the accelerator tunnel, an optics hutch on the experiment hall, a visible light transport line, and an X-ray transport line in the optics hutch. The visible and UV light is extracted by a mirror in a vacuum chamber installed between the front end and the X-ray transport line (Fig.1). The visible and UV light extracted is transported in the bent shielded pipe out of the optics hutch to a dark room on the experiment hall. In the dark room, single bunch impurity is measured by a gated photon counting method, which utilizes fast Pockels cells for switching light pulses, and bunch length is measured by a streak camera.

The X-ray transport line (Fig. 1) has a double crystal monochromator. It covers the energy range of 4 to 14 keV by Silicon (111) reflection. The monochromator crystals and their mechanisms can be moved off the photon beam axis in the monochromator vacuum chamber when use is made of white X-rays. 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 wavefront of X-ray synchrotron radiation. Therefore, all the components of the X-ray transport line are in vacuum chambers under UHV pressure. The X-ray transport line has been designed so that it can be used not only for beam diagnostics but also for synchrotron radiation experiments on accelerator components such as photon absorbers. There are two dummy vacuum pipes, which can be replaced by specific chambers for such experiments.

ZONE PLATE BASED X-RAY BEAM PROFILE MONITOR

In order to measure the size of the electron beam of the SPring-8 storage ring, we have installed a beam profile monitor based on an X-ray zone plate in the X-ray transport line of the diagnostics beamline I(BL38B2). The resolution target of the beam size measurement is 1 micron (1σ).

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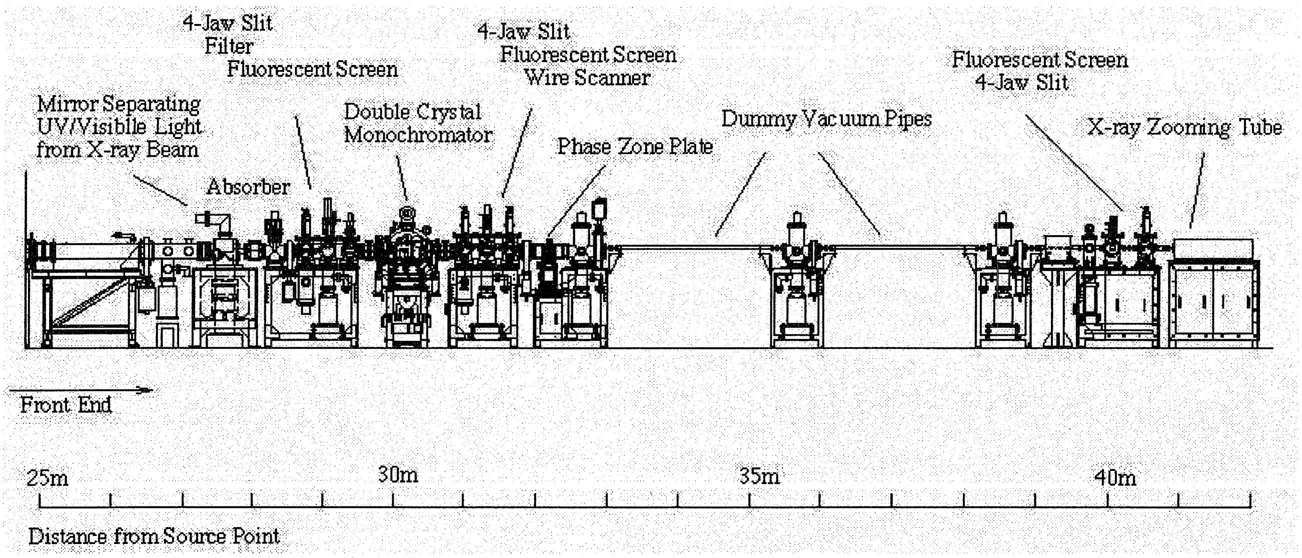

Figure 1: X-ray transport line of the SPring-8 diagnostics beamline I (BL38B2). All the components are in the optics hutch.

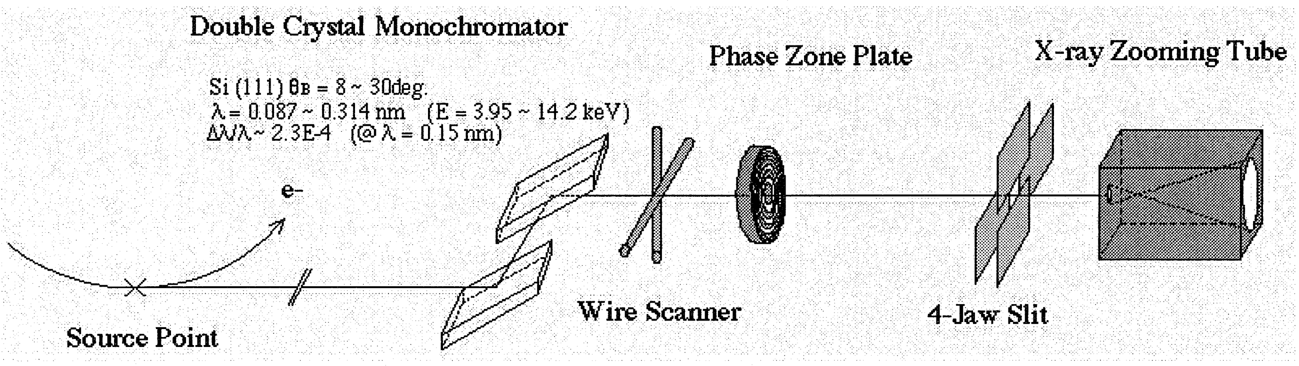

Figure 2: The optical system of the X-ray beam profile monitor based on a zone plate.

The optical system of the X-ray beam profile monitor is shown in Fig. 2. The synchrotron radiation emitted by the electron beam moving in a dipole magnet is imaged by a single phase zone plate. Monochromatic X-ray at an energy of 8.2 keV is selected by the double crystal monochromator. The magnification factor of the zone plate is about 0.27, and an X-ray zooming tube is used as a detector to compensate for demagnification. The distance between the source point and the zone plate is 32.2m, while that between the zone plate and the input photocathode of the X-ray zooming tube is 8.8m. Crossed wires made of tungsten mounted on a wire scanner are placed in front of the zone plate as a center stop, and a 4-jaw slit is placed in front of the X-ray zooming tube as an order selecting aperture.

The phase zone plate was fabricated by NTT Advanced Technology Co. The characteristics of the zone plate are summarized in table 1. The total number of zones is 468, and the width of the outermost zone is 0.75 μm. The thickness of the zone material, tantalum, was optimized to obtain maximum diffraction efficiency. The X-ray zooming tube (Hamamatsu Photonics K. K., C5333) has resolution better than 0.5 μm (FWHM) at the input photocathode, which is sensitive to X-rays below 10keV.

Table 1: Parameters of the phase zone plate

Diameter	1.4 mm
Number of zones	468
Outermost zone width	0.75 μm
Zone material	Tantalum
Zone thickness	2.0 μm
Focal length*	6.92 m
Diffraction Efficiency *	32 %
Spatial Resolution* (1σ)	1.5 μm

*Calculated Value at E = 8.2 keV (λ= 0.15 nm).

EXPERIMENTS

The focal length of a zone plate is proportional to the photon energy. We focus the zone plate by changing the output photon energy of the double crystal monochromator. In Fig. 3 we show the results from the initial experiments. The horizontal size σ_x of a beam

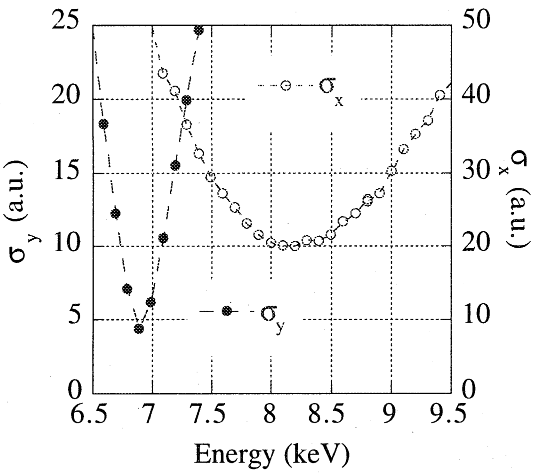

Figure 3: Horizontal and vertical sizes of a beam image, as a function of photon energy, measured before improvement of the monochromator crystal holders.

image was minimum at an energy of 8.15 keV, while the vertical size σ_y was minimum at a significantly lower energy of 6.9 keV. The photon energy of 8.15 keV giving minimum horizontal beam size was consistent with the design of the zone plate. However, the zone plate was out of focus at 6.9 keV and additional lenses were necessary to obtain a focused image of the electron beam in the vertical direction. After the initial imaging experiments, flatness of the monochromator crystals was examined. It was confirmed that the crystals were bent by clamping to the holders, and the shift of energy giving minimum vertical size was attributed to small bend of the crystals.

The crystal holders of the monochromator have been improved to cure the bend of the crystals. The results of imaging experiments after improvement of the crystal holders are shown in Fig.4. Both the horizontal and the

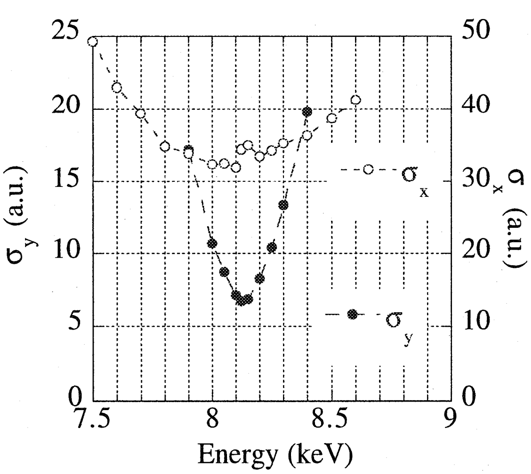

Figure 4: Horizontal and vertical sizes of a beam image, as a function of photon energy, measured after improvement of the monochromator crystal holders.

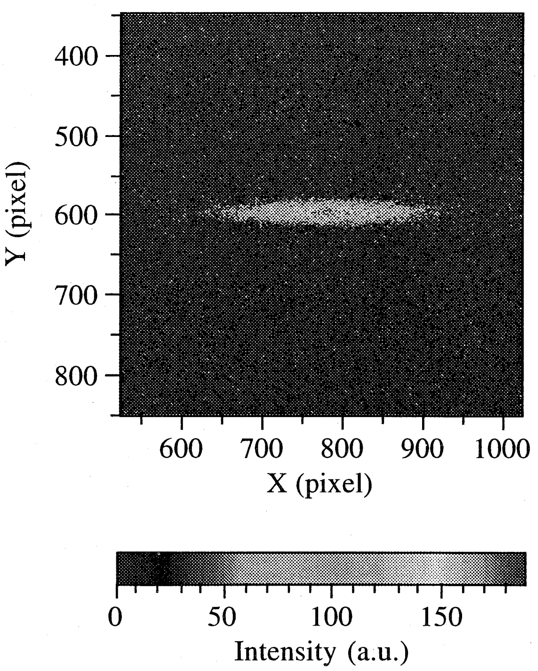

Figure 5: An example of images of electron beam of the SPring-8 storage ring observed by the zone plate X-ray beam profile monitor.

vertical sizes of a beam image are minimum at an energy of about 8.15 keV, which is consistent with the design of the zone plate. The bend of crystals which initially affected the vertical beam profile has been cured, and a focused image of the electron beam has been successfully obtained. In Fig. 5 we show an example of images of electron beam of the SPring-8 storage ring observed by the zone plate X-ray beam profile monitor. The filling mode was the multi-bunch mode, and the total beam current was 100 mA. The gaps of all the insertion devices were opened. The shutter time of the X-ray zooming tube was 1ms. Based on preliminary calibrations of the X-ray zooming tube, the horizontal and vertical beam sizes (1σ) were roughly estimated to be 120 μm and 15 μm, respectively. More accurate evaluation of the beam size awaits for careful characterization and calibration of the X-ray zooming tube.

REFERENCES

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