PLANNED X-RAY IMAGING OF THE ELECTRON BEAM AT THE SPRING-8 DIAGNOSTICS BEAMLINE BL38B2

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Abstract

X-ray imaging observation of the electron beam is planned at the SPring-8 storage ring diagnostics beamline BL38B2 to evaluate small vertical emittance. The resolution target is 1 micron of electron beam size (1σ). The synchrotron radiation from a dipole magnet source will be imaged by a single phase zone plate. Monochromatic X-ray with energy of 8keV will be selected by a double crystal monochromator. The magnification factor of the zoneplate is 0.27, and an X-ray zooming tube will be used as a detector to compensate for demagnification.

1 INTRODUCTION

Measurement of small vertical size of electron beam is among the most challenging subjects of accelerator beam diagnostics of low emittance synchrotron radiation sources. At the SPring-8 storage ring, the high energy of electrons, 8 GeV, collimates synchrotron radiation in a narrow vertical divergence angle, and diffraction effect severely limits the resolution of conventional electron beam imaging with visible light[1].

The resolution is significantly improved by utilizing synchrotron radiation in shorter wavelength regions. X-ray imaging observation of the electron beam is planned at the SPring-8 storage ring diagnostics beamline BL38B2 to evaluate small vertical emittance.

2 DIAGNOSTICS BEAMLINE BL38B2

The beamline BL38B2 is dedicated for accelerator beam diagnostics and R&D of accelerator components. It has a bending magnet light source, and wide band spectral availability including visible/UV light, and soft and hard X-rays is anticipated. The beamline consists of a front end in the accelerator tunnel, an optics hutch in the experiment hall, a visible light transport line transporting visible/UV light from the optics hutch to a dark room, and an X-ray transport line in the optics hutch. The visible light transport line was completed in 2000, and longitudinal diagnostics of the electron beam such as bunch length and single bunch impurity are available.

Installation of the X-ray transport line is now under way. It has a double crystal monochromator, which can be moved off the beam axis when use is made of white, including both soft and hard, X-rays. Electron beam imaging with monochromatic X-ray is planned to evaluate small vertical emittance of the SPring-8 storage ring. The X-ray transport line as well as the front end has no windows, which potentially could distort wavefront and degrade imaging resolution, or obstructs soft X-ray and visible/UV light.

3 BEAM IMAGING WITH X-RAY

3.1 Why Phase Zone Plate ?

The resolution target of the beam size measurement is 1 micron (1σ). Assuming the vertical betatron function β_y of 30m at the source point, it corresponds to the resolution of vertical emittance ε_y of 33 fm•rad.

In the initial stage of the design study of the diagnostics beamline BL38B2, an X-ray pinhole camera was proposed. The positions of the pinhole and the camera were 17.2m (front end) and 34.4 m (X-ray transport line), respectively, from the source point. In order to optimize the observing photon energy and the size of the pinhole, we calculated an image of a single electron numerically and concluded that the diffraction limited resolution of the X-ray pinhole camera is no smaller than 10 µm (Fig. 1).

The alternative is to use an imaging optical element. If the electron beam is imaged by utilizing full vertical divergence of synchrotron radiation, it is necessary to

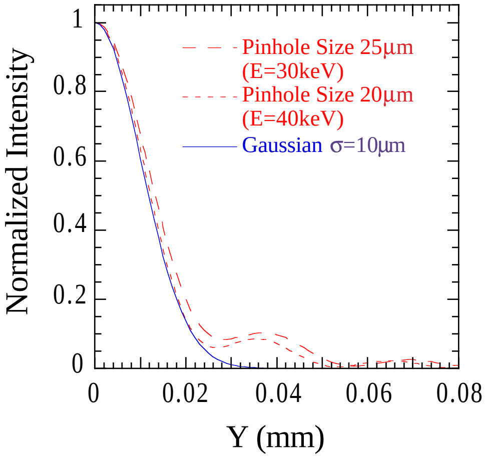

Figure 1: Computed intensity distributions of a single electron imaged by X-ray pinhole camera. The magnification factor is one.

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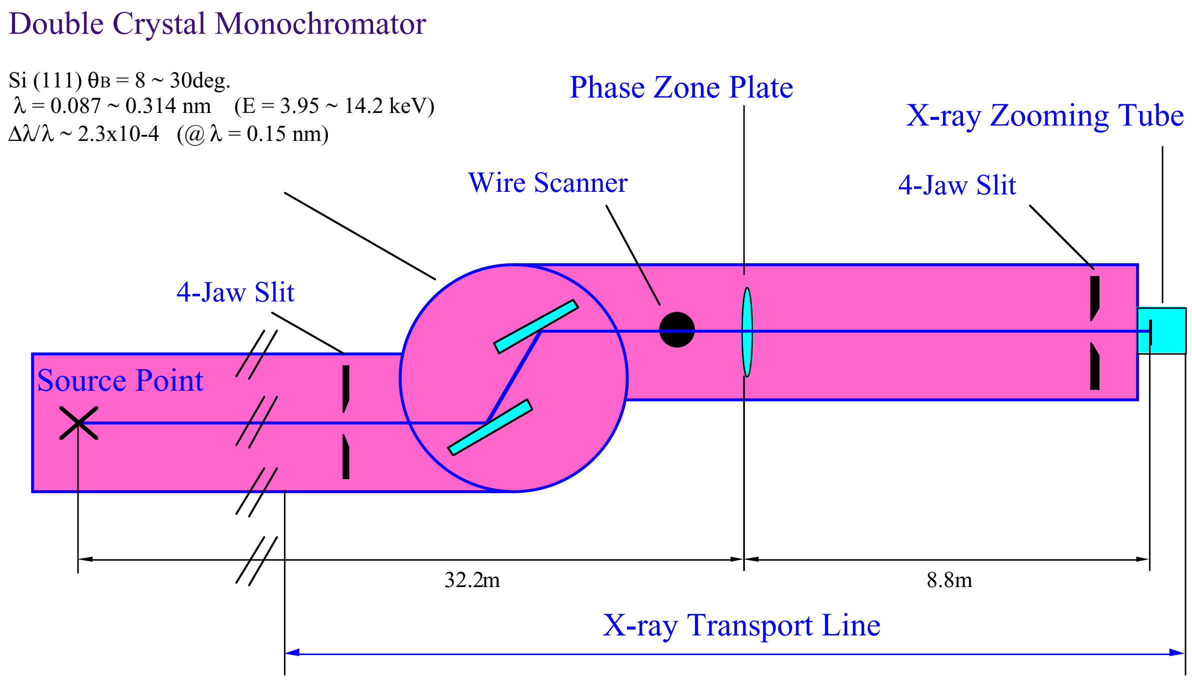

Figure 2: The optical system of the X-ray beam size monitor. All the components are installed in the optics hutch.

observe at photon energies higher than 1 keV to achieve resolution better than 1µm. If we observe at higher photon energies around 10 keV, necessary numerical aperture is much smaller than the vertical divergence of synchrotron radiation, and degradation of resolution caused by contamination of π polarized component can be ignored. In the hard X-ray region, a phase zone plate achieves superior spatial resolution.

3.2 Optical System

The optical system of the X-ray beam size monitor is shown in Fig. 2. Monochromatic X-ray is selected by a double crystal monochromator. A single phase zone plate images the electron beam on the input photocathode of an X-ray zooming tube. The magnification factor is 0.27.

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).

The phase zone plate was fabricated by NTT Advanced Technology Co. The characteristics of the zone plate is summarized in table 1. The thickness of the zone material 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.

3.3 Imaging Properties of the Phase Zone Plate

The spatial resolution of the phase zone plate was calculated based on wave optics. A point source of spherical wave was assumed at the bending magnet

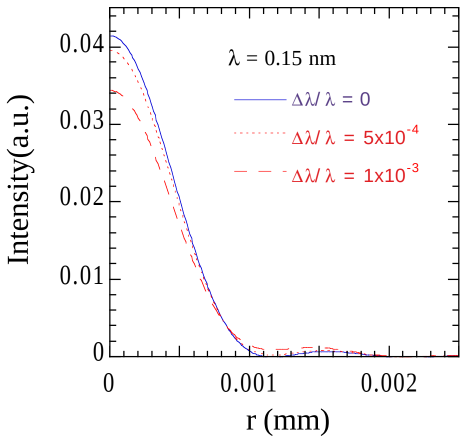

Figure 3: Computed intensity distributions of a point source imaged by the phase zone plate at the tuned and detuned wavelengths. The magnification factor is 0.27.

source point. The focusing of the zone plate was simulated by multiplying a complex factor which takes into account both phase shift and attenuation of the electric field in the zone material, and propagation of light to the photocathode of the X-ray zooming tube was calculated by diffraction formula. Figure 3 shows intensity distributions of diffraction limited image of the point source at the tuned and detuned wavelengths. At the tuned wavelength, the diffraction limited image is in good agreement with that obtained by an ideal lens, and best fitted Gaussian curve has a width (1σ) of 1.5 μm in the source coordinates. The images at detuned wavelengths show chromatic aberration of the zone plate. It is necessary to use monochromatic light with bandwidth narrower than $1*10^{-3}$, which is attainable by the double crystal monochromator.

3.4 Effects of Electron Beam Divergence

An electron moving in magnetic field of a bending magnet is not a point source of light in a strict sense. Therefore synchrotron radiation emitted by a single electron is not an ideal spherical wave. Figure 4 shows electric field of synchrotron radiation at the position of the zone plate, which was calculated from Lienard-Wiechart potentials of an electron moving on ideal orbit in a bending magnet. In the horizontal direction, distribution of phase of synchrotron radiation is different from that of ideal spherical wave. If the orbit has an angle at the source point, it will affect the image of the electron. In the vertical direction, distribution of phase of synchrotron radiation is in good agreement with that of ideal spherical wave. It is anticipated that an angle of the orbit will not affect the image.

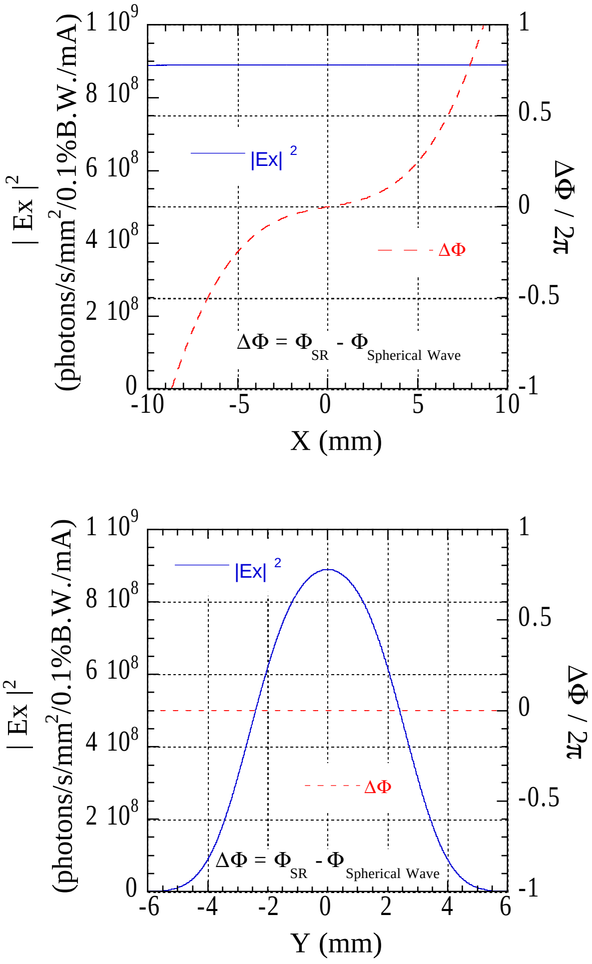

Figure 4: Electric field of synchrotron radiation at the position of the phase zone plate (σ polarized component).

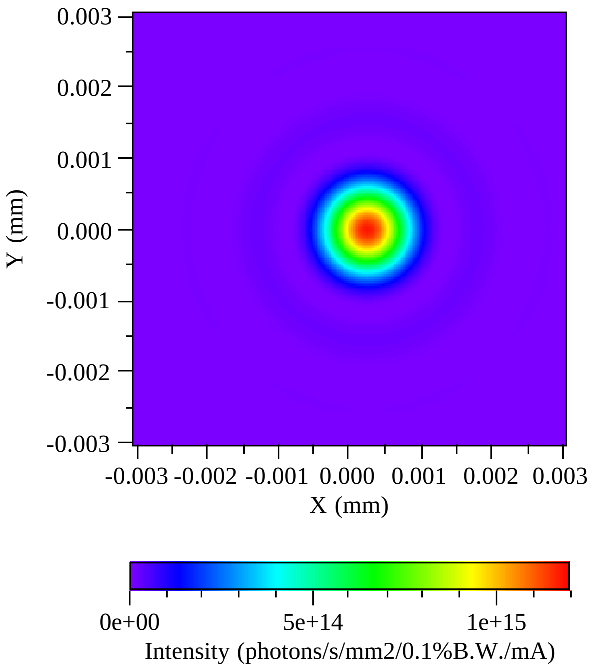

Figure 5: Image of a single electron moving on an orbit with angles at the source point ($\Delta\theta_x = 0.2$ mrad, $\Delta\theta_y = 1.0$ μrad, see text). Magnification is 0.27.

In order to evaluate effects of angular divergence of electron beam on imaging, we calculated an image of a single electron moving on an orbit which has angles at the source point (Fig. 5**).** The horizontal angle $\Delta\theta_x$ and the vertical angle $\Delta\theta_y$ are 0.2 mrad and 1.0 μrad, respectively, which approximate 2σ of designed angular divergences of the electron beam. The size of the image in Fig. 5 is in good agreement with that of a point source shown in Fig. 3. However , the position of the image is apparently shifted in the horizontal direction. Thus convolution of beam angular divergence could degrade resolution of horizontal imaging. However, degradation of horizontal imaging resolution by beam angular divergence amounts to at most 0.5 μm, which is still negligibly smaller than the measured horizontal beam size σ_x of about 150 μm.

REFERENCES

[1] M. Masaki and S. Takano, “Diffraction Limited Resolution of a Synchrotron Radiation Beam Profile Monitor”, SPring-8 Annual Report 1997, p169.