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SYNCHROTRON LIGHT DIAGNOSTIC BEAMLINE DESIGN FOR HEPS STORAGE RING*

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Abstract

High Energy Photon Source (HEPS) is a 6 GeV ultralow-emittance storage ring light source to be built in Beijing, China. With a multiple-bend achromat lattice design, the storage ring is expected to achieve an ultralow emittance of 34 pm.rad. The horizontal and vertical beam sizes will be in the sub-10 µm level. Beam emittance will be measured with x-ray diagnostic beamline at a low dispersion bending magnet source point. A visible light beamline will be designed to measure the bunch length and purity. In this paper, we will introduce the x-ray beamline, which combine with different techniques to resolve beam sizes and emittance.

INTRODUCTION

HEPS is a 6 GeV ultralow-emittance storage ring light source [1]. It is expected to achieve 34 pm·rad ultralow-emittance with MBA (Multiple-Bend Achromat) lattices design for constructing a diffraction-limited storage ring [2]. Both horizontal and vertical beam sizes of HEPS storage ring will be in the sub-10 µm level. An x-ray beamline will be designed for beam sizes and emittance measurement at a low dispersion location. Bunch length is measured by streak camera at another beam diagnostic beamline in visible to UV radiation region. Various techniques will be used to measure the beam size, such as x-ray pinhole imaging [3], x-ray Fresnel diffractometry [4], KB mirror focusing imaging[5], vis-UV π-polarization imaging and double-slit interferometry.

X-RAY BEAMLINE SETUP

A schematic of the x-ray diagnostic beamline layout is showed in Fig.1. It will be located at the RF where no ID is planned to be installed. The source point is in the first dipole (BLG1) after the straight sections, 1mrad inside the edge to avoid edge radiation. Table 1 lists some designed parameters of the source point. With high vertical beta-function and no dispersion, the source sizes are dominated by contributions from beam emittance. X-ray pinhole imaging and KB mirror imaging are used compatibly for beam sizes measurement. For further update, x-ray Fresnel diffractometry is a good candidate to achieve required high spatial resolution, its slits can be easily added to the pinhole mask with larger slits width.

Table 1: Designed Parameters of the Source Point

Parameters	Value
Energy	6 GeV
Beam current	200 mA
Bending radius	41.4 m
Horizontal Emittance	34.2 pm·rad
Emittance Coupling	10%
Beta function β_x	1.3 m
Beta function β_y	24.3 m
Horizontal beam size	6.7 µm
Vertical beam size	9.1 µm

A set of pinhole slits are place in an optical box about 5.8m from the source point. The optical box is mounted onto motorized stages, allowing to exchange the optical systems and to align the optics with respect to the beam axis in four degrees of freedom: two linear translations perpendicular to the beam axis, a goniometer rotation around the horizontal axis, and a rotation around the vertical axis.

A pair of KB mirrors is mounted on adjustment mechanics, installed in an independent vacuum chamber, which is 18 m from the source point and 18 m to the detector. We use 1:1 imaging in the KB system with two cylindrical mirrors. With 2~3 mrad grazing incidence angle, the two mirrors would reflect the x-ray beam respectively 4~6 mrad horizontal and vertical from the incidence x-ray line.

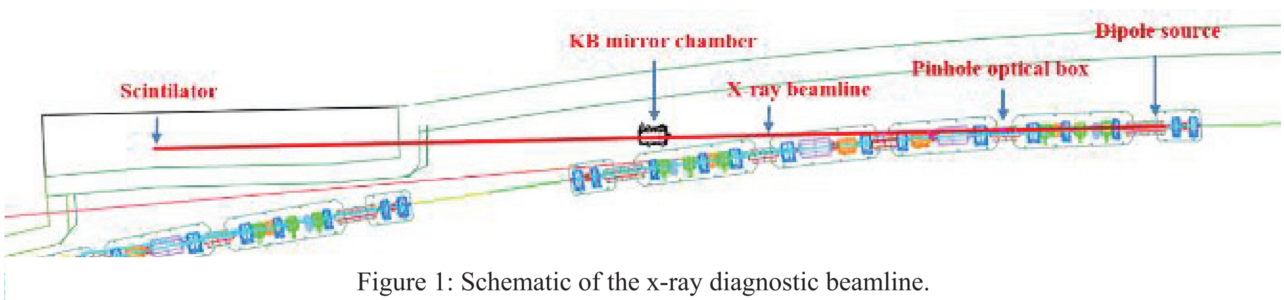

Figure 1: Schematic of the x-ray diagnostic beamline.

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A scintillator camera is located 36 m away from the source point in an optical hutch. In order to minimize chromatic effects in the x-ray pinhole imaging system or Fresnel diffractometry, a Si crystal monochromator will be installed in front of the scintillator camera. It can be moved in and out of the photon beam by a linear translation stage.

The main functions of the front-end (FE) are vacuum protection of the storage ring, defining the angular acceptance of beamline and absorption of heat. Standard front-end components such as collimator, water-cooled shutter, gate valves, fast shutter, safety shutter, fixed mask will be used in the x-ray diagnostic beamline.

RESOLUTION OF X-RAY OPTICS

X-ray Pinhole Camera

The most robust and simplest system is x-ray pinhole camera, which has been widely used at several machines. The PSF of the pinhole camera is calculated by convolution the geometric shadow and Fraunhofer diffraction. It is a balance between geometric blurring and the diffraction limit. The optimum aperture that minimize the PSF can be obtained by making the two values equal. A more accurate model to calculate the PSF from the pinhole is to compute the illumination on a screen through the pinhole from a source point using the Fresnel diffraction approximation [3].

In order to optimize the pinhole sizes to achieve the best resolution, Synchrotron Radiation Workshop (SRW) [6] has been used to simulate the pinhole optics. The curve for calculated PSF dependence on the pinhole size is shown in Fig. 2. It shows that a smaller PSF comes from the higher photon energy. The best PSF of ~5.8 microns is achieved with a pinhole size of about 14 microns at 45 keV.

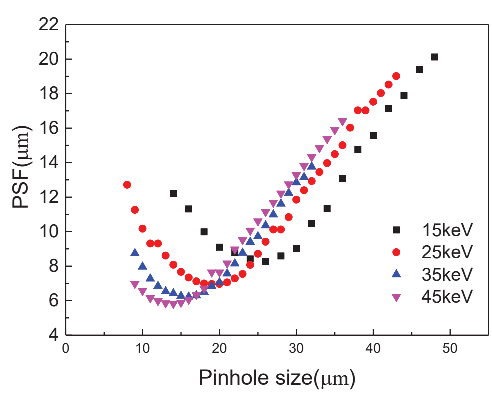

Figure 2: SRW simulations of PSF rms width vs. pinhole size for several photon energy.

X-ray Fresnel Diffractometry

The X-ray Fresnel diffractometry, developed at Spring-8 [4], is a good method for ultralow emittance diagnostics. When optimize the slit aperture A to satisfy the Fresnel approximation using equation (1), a double-lobed PSF with the deepest median dip could be created. It could be used compatible with pinhole camera easily by changing the pinhole width.

$$A \approx \sqrt{7\lambda \frac{LR}{L+R}} \quad (1)$$

Beam size information will be contained in the double lobes. The beam size can be calculated by comparing with the theoretical model. In our simulation, the source-to-slit distance L is 5.6 m, the slit-to-detector distance R is 16.8 m, the optimized slit width is 49.4 μm at 15 keV photon energy. Figure 3 shows the simulated beam profiles by SRW for source sizes from 1 μm to 20 μm. Figure 4 shows the peak-to-valley intensity ratio curves as the function of beam sizes, for x-ray photon energy of 8 keV, 15 keV, 30 keV and 40 keV with optimized slits width. The peak-to-valley ratio becomes sensitivity as the x-ray photon energy goes harder, it shows high sensitivity to μm-order changes at 40 keV.

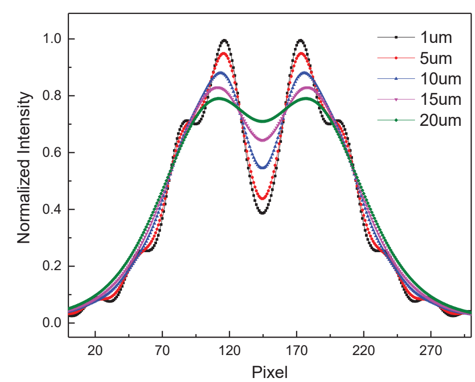

Figure 3: SRW simulations of beam profiles for different source sizes.

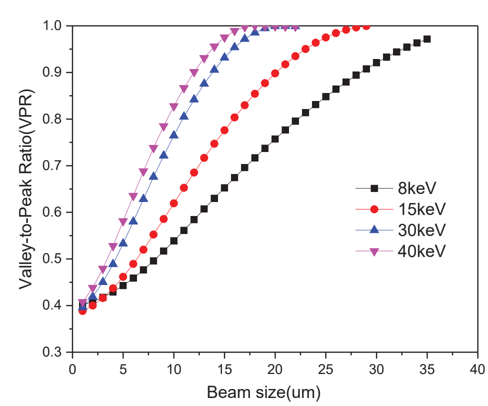

Figure 4: Peak-to-valley ratio vs. source size at 8 keV, 15 keV, 30 keV and 40 keV.

KB Mirror

KB mirror monitor is also considered in the x-ray diagnostic beamline. Just like the history of camera, lens based camera replaced the pinhole camera because of larger ac-

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ceptance angle of light. Compared with x-ray pinhole camera, KB mirror monitor has larger numerical aperture (NA), which specifies the light-gathering power of the imaging system, means improvement of diffraction limits.

KB mirror monitor has some specific advantages. First, it has no chromatic aberration; therefore, it is not necessary to use a monochromator, and a higher flux is obtained, resulting in a higher signal-to-noise ratio. Second, the KB mirror can operate in the hard X-ray region, so diffraction makes a smaller contribution to the spatial resolution. Further, it can acquire a direct image of an electron beam, which can provide considerable information on the beam. Not only can the beam size in both directions be acquired, but also the operator can easily observe the beam motion, broadening, or tilt status.

The accuracy of the KB mirror monitor is determined by the rms PSF. The obtained image on the camera is the convolution of the source profile with the PSF of the entire system, which includes several independent terms: the PSF of the diffraction, the spatial resolution of the X-ray camera, and the image blur caused by the mirror slope error. We calculate the PSF assuming that the source and the PSF are Gaussian. Let us denote the RMS Gaussian size of the image as Σ; then it can be expressed as follows:

$$\begin{aligned} \Sigma^2 &= \left(\sigma \times M\right)^2 + S_{diff}^2 + S_{slope}^2 + S_{camera}^2 \\ &= \left(\sigma \times M\right)^2 + S_{sys}^2 \end{aligned} \quad (2)$$

Where σ is the RMS size of the image of the photon source at the bending magnet, M is the magnification of the KB mirror. S_{diff} is the diffraction introduced by the mirror slope error, it's a dominant item depending on the mirror machining quality. With the best commercially available mirror of 0.05 μrad slope error, S_{slope} is ~1.8 μm in our design. S_{camera} is the rms spatial resolution of the X-ray camera, chould be less than 1.5 μm with 10 μm thick YAG:Ce or LuAG:Ce scintillator and macro lens. S_{sys} is the effective rms PSF of the entire system, is ~2.4 μm.

CONCLUSION

This article presents the initial design of the x-ray diagnostic beamline for beam sizes and emittance measurement for HEPS. Sub-10 μm level beam sizes should be resolved, x-ray monochromatic pinhole camera, Fresnel diffractometry and KB mirror are considered to be compatible used in this beamline. Each method has its unique characteristic, will be used at different conditions.

REFERENCES

[1] G. Xu, X.H. Cui, Z. Duan *et al*., "Progress of the Lattice Design and Physics Studies on the High Energy Photon Source", in *Proc. IPAC'17,* Copenhagen, Denmark, May 2017, paper WEPAB052, pp. 2697-2699, doi:10.18429/JACoW-IPAC2017-WEPAB052

[2] Jiao. Y *et al.*, "Evolution of the lattice design for the High Energy Photon Source", in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, BC, Canada, Apr.-May 2018, pp. 1363-1366. doi:10.18429/JACoW-IPAC2018-TUPMF049

[3] Thomas, Cyrille *et al.*, "X-ray pinhole camera resolution and emittance measurement", *Physical Review Special Topics-Accelerators and Beams* 13.2, 2010, 022805. doi: 10.1103/PhysRevSTAB.13.022805

[4] Masaki, Mitsuhiro *et al.*, "X-ray Fresnel diffractometry for ultralow emittance diagnostics of next generation synchrotron light sources", *Physical Review Special Topics-Accelerators and Beams* 18.4, 2015, 042802. doi: 10.1103/PhysRevSTAB.13.022805

[5] D. C. Zhu *et al.*, "Performance of beam size monitor based on Kirkpatrick–Baez mirror at SSRF", *Nuclear Science and Techniques* 29.10, 2018, 148. https://doi.org/10.1007/s41365-018-0477-y