BEAM SIZE MONITOR FOR TPS

Chien-Kuang Kuan, Tse-Chuan Tseng, I Ching. Sheng, Shen-Yaw Perng, June-Rong Chen
National Synchrotron Radiation Research Center, Hsinchu, Taiwan

Abstract

Third-generation light source TPS under construction in NSRRC has two diagnostic beamlines in the storage ring. Visible SR interferometers and X-ray pinhole cameras are widely used to measure the transverse beam profile in synchrotron light sources. In phase I we shall adopt both methods for application as beam-size monitor. The visible SR interferometer uses a double slit to obtain a one-dimensional interference pattern along the horizontal or vertical axis. A simple X-ray pinhole camera is designed to measure the size, emittance and energy spread of the electron beam. In this paper we present the design and calculation of these two beam-size monitors for TPS.

INSTRODUCTIONS

Taiwan Photon Source (TPS) is under construction at National Synchrotron Radiation Research Center (NSRRC). The electron beam stored in the storage ring of circumference 518 m has energy 3 GeV and current 500 mA. In phase I we shall have two diagnostic beamlines, using radiation from a bending magnet: one is a dedicated diagnostic beamline; the other is constructed together with the bending beamline. The rms beam sizes at these places are theoretically 40 μm in the horizontal plane and 16.5 μm in the vertical plane for 1 % coupling. We adopt two methods to measure the beam size -- a visible SR interferometer and an X-ray pinhole camera.

Both methods of measuring the beam size are simple, cheap and reliable, and can measure the vertical beam size of 16.5 μm. The visible SR interferometer [1,2] has better resolution than the X-ray pinhole camera [3], but is constrained by the maximum opening angle between the slits. The X-ray pinhole camera is an imaging system. There are many effects on the point spread function (PSF) in the imaging system, including diffraction and pinhole dimension. The deconvolution of the PSF determines the smallest image size measurable with the imaging system. We use the X-ray pinhole camera to measure the beam size, emittance and energy spread of the electron beam.

If the coupling is down to 0.1%, the rms beam size is theoretically 5.2 μm in the vertical plane. It is difficult to measure accurately a beam size in this range with these two methods; it is possible, but must be done carefully: there are too many constraints and errors induced by the optical components. In this paper we present the design, calculation and smallest resolution of the beam size for these two beam size monitors for TPS.

VISIBLE SR INTERFEROMETER

Figure 1 shows the layout of the visible SR interferometer. This interferometer is based on an investigation of the spatial coherence of SR. An interferogram in the CCD is shown in fig. 2; fitting the interferogram yields visibility γ from Eq. (1):

$$\text{Visibility } V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} = \frac{2\sqrt{I_1 I_2}}{I_1 + I_2}|\gamma| \tag{1}$$

The beam size σ_{beam} comes from the relation [1],

$$\sigma_{beam} = \frac{\lambda \cdot R}{\pi \cdot S} \cdot \sqrt{\frac{1}{2} \cdot \ln\left(\frac{1}{\gamma}\right)} \tag{2}$$

in which λ is the wavelength of the observation, *R* is the distance from the light source to the double slit, and *S* is the slit separation.

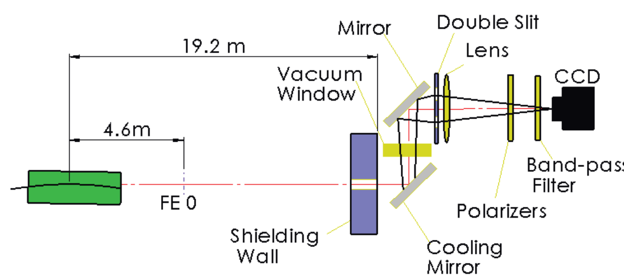

Figure 1: Layout of the visible SR interferometer.

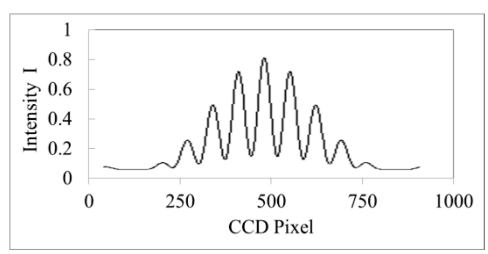

Figure 2: Interferogram in the CCD.

The parameters used are wavelength λ = 500 nm, distance *R* = 20 m, and maximum possible visibility γ = 0.97. With these values inserted into Eq. (2), the possible resolution of the beam size depends on the slit separation *S* as shown in fig. 3. Using *S* = 70 mm and visibility γ = 0.97, the beam size is about 5 μm. The opening angle between the slits, 70/20 = 3.5 mrad, is constrained by the bending chamber; the minimum gap in the bending chamber of the TPS case is 3.8 mrad. The main error of the visible SR interferometer arises from the distortion of the mirror by the radiation power. We use a cooling mirror made of Be to diminish the mirror distortion. With visibility γ=0.97, the background of noise in the CCD

ISBN 978-3-95450-119-9

affects the accuracy of measurement of the beam size. The CCD will be tested and calibrated before use.

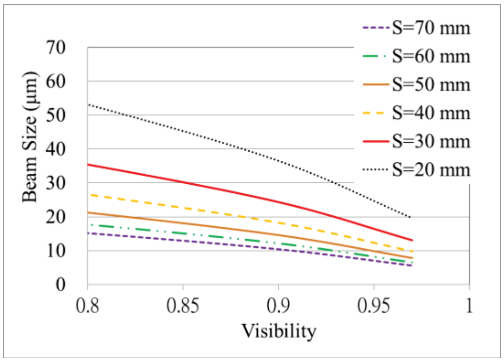

Figure 3: Calculation of the beam size with varied slit separation S and visibility γ.

X-RAY PINHOLE CAMERA

Figure 2 shows the layout of the X-ray pinhole camera; the distance from the light source radiated by the bending magnet to the zero point of the front end (FE) is 4.6 m, from the light source to the shielding wall is 19.2 m.

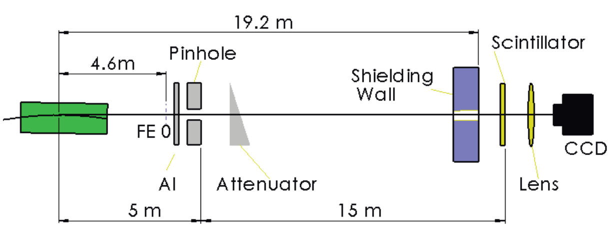

Figure 4: Layout of the X-ray pinhole camera.

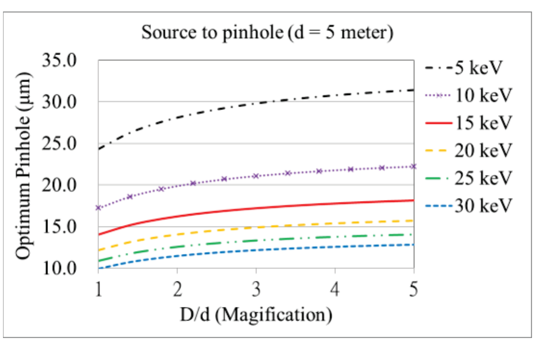

Figure 5: Optimum pinhole dimension with varied magnification D/d and varied energy at fixed length d.

To increase the resolution of the beam size, a smaller length d from the light source to the pinhole is better, whereas a greater length D from the rectangular pinhole to the scintillator is better [3]. The smallest length for a possible place to install the pinhole is d = 5 m from the light source. The greater is length D, the weaker is the intensity of the image into the CCD. We must hence compromise between length D and the intensity of the image. From fig. 5, the magnification $M = D/d$ increases little for M larger than 3. We put the scintillator, $CdWO_4$ and YAG:Ce, at length D = 15 m; the magnification M is then equal to 3.

The photon energy is filtered with Al material. The transmission ratio is shown in fig. 6. We filter the photon energy with this Al material of varied thickness to obtain the photon flux in fig. 7. To use Al with thickness < 3 mm, photon flux > 10^{-6} photon/s [4] and a $CdWO_4$ screen gives a compromise between the CCD and the energy range; the ultimate value depends on the final choice of CCD type.

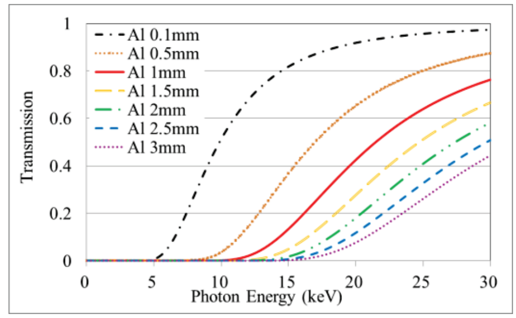

Figure 6: Transmission ratio of material Al of varied thickness.

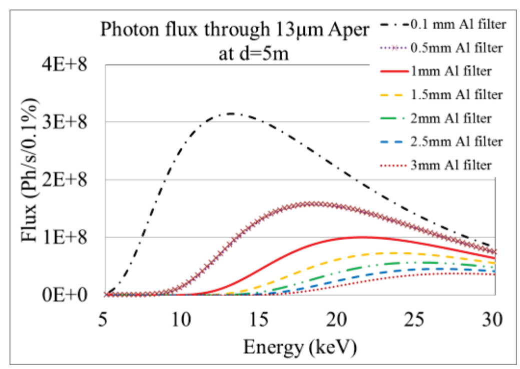

Figure 7: Photon flux after the Al filter with varied thickness at fixed aperture 13 μm.

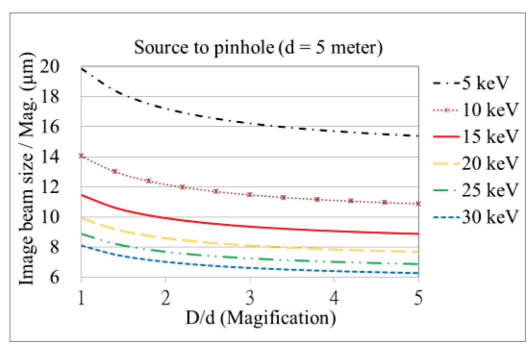

Figure 8: Image beam size divided by M with varied M and varied energy at fixed length d.

Figure 8 shows the size of the source beam, obtained on dividing the size of the image beam by M; we can have the measuring resolution of the beam size. The relation of filter, energy and pinhole with measurement resolution of the source beam size is summarized in Table 1.

ISBN 978-3-95450-119-9

Table 1: Resolution of the source beam size

	Al filter /mm						
	0.1	0.5	1	1.5	2	2.5	3
maximum energy /keV	13.0	18.3	21.5	23.0	25.0	26.5	27.1
optimum pinhole /µm	18.5	15.6	14.5	13.9	13.3	12.9	12.8
image beam size/*M* /µm	10.1	8.5	7.8	7.6	7.3	7.0	7.0

With varied photon energy, length *d* and magnification *M*, the pinhole has varied resolution of the beam size. With fixed length $d = 5$ m, $M = 3$ and thickness of the Al filter less than 3 mm, the minimum source beam size is located between 10 and 20 µm of the pinhole dimension, as shown in fig. 9.

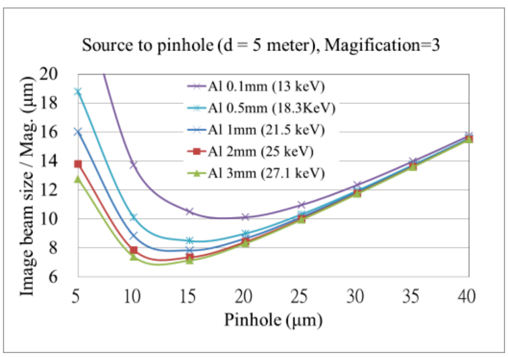

Figure 9: Calculated resolution of the beam size [3].

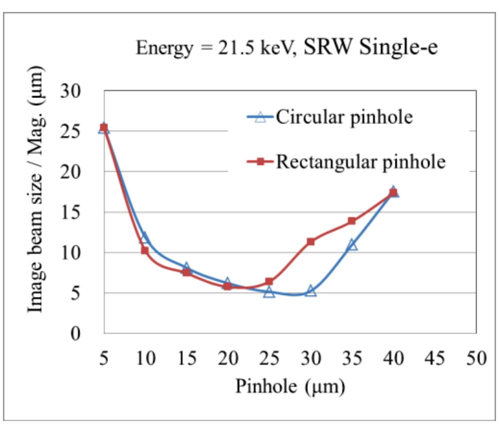

Figure 10: Resolution of the beam size with program SRW and a single electron.

We use the program SRW [5] to simulate the resolution of the beam size, with energy 21.5 keV and the profile fitted with a Gaussian shape. Figure 10 using the single-electron mode, the data is near the calculation at the pinhole 15µm. Figure 11 using the multi-electron mode, the data is larger than calculated. The minimum source beam size is between 10 and 25 µm of the pinhole dimension.

To align the pinhole, there are two methods: one is an adjustable pinhole; the other is a pinhole array. We shall use the pinhole array with vertical separation 0.5 mm and horizontal separation 1 mm to prevent overlap of the light from adjacent pinhole. The first choice of pinhole dimension is 15 µm, varied pinhole dimension between 10 and 25 µm.

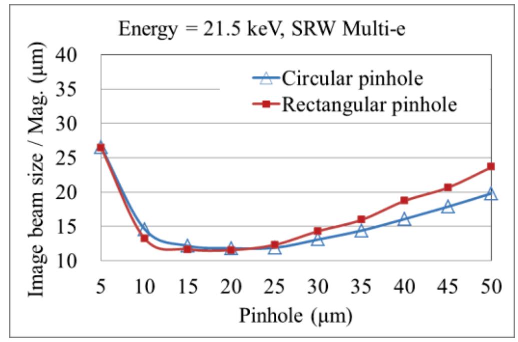

Figure 11: Resolution of beam size with program SRW and multiple electrons.

DISCUSSION

The main design parameters of the beam size monitor for TPS are set. Both a visible SR interferometer and an X-ray pinhole camera are used to measure the beam size of the TPS project. From the analysis a beam size larger than 10 µm is easily measured with the two methods at TPS. For the purpose of machine study, the beam size can be adjusted below 10 µm. In the range of beam size 10 to 5 µm, the relative design parameters should be carefully adjusted. A beam size less than 5 µm is difficult to measure.

ACKNOWLEDGEMENTS

We thank colleagues, particularly the Precision Mechanical, Beam Dynamics, Instrumentation & Control and Vacuum Groups, for helpful discussion.

REFERENCES

[1] T. Mitsuhashi and M. Tadano, "Construction of a SR Monitor for the Photon Factory Advanced Ring", Proceedings of the 2003 Particle Accelerator Conference, 2003, pp. 2506-2507.

[2] T.C. Tseng et al., "The SRI beam size monitor developed at NSRRC", PAC 05, Knoxville, Tennessee, USA, 2005.

[3] P. Elleaume et al., "Measuring Beam Sizes and Ultra Electron Emittances Using an X-ray Pinhole Camera", J. Synchrotron Rad., 1995, pp. 209-241.

[4] C. A. Thomas and G. Rehm, "An X-Ray Pinhole Camera System for Diamond", in Proceedings of DIPAC '05, Lyon, France, 2005.

[5] O. Chubar and P. Elleaume, "Accurate and Efficient Computation of Synchrotron Radiation in the Near Field Region", EPAC98, THP01G, 1998, pp.1177-1179.

ISBN 978-3-95450-119-9