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A Pinhole Camera for SPEAR 2

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A PINHOLE CAMERA FOR SPEAR 2

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Abstract

A new pinhole camera system has been installed on Spear 2 to measure its vertical emittance. The hard X-rays from a bending magnet source point are imaged on a phosphor screen through a 30 um x 25 um pinhole aperture. The resolution of the system for 8 keV photons is limited to 31.2 um by Fraunhoffer diffraction and is much smaller than the 340 um FWHM vertical beam size corresponding to 0.9% vertical coupling. Measurements are presented. Optimal pinhole location and hole size are discussed.

1 INTRODUCTION

Spear is a 28 year old electron ring built for high energy physics research which was progressively converted to a synchrotron radiation source. Its present horizontal emittance of 135 nm [Nuhn, Safranek] is about the minimum achievable emittance for this FODOF/ IR lattice. The two families of skew quadrupoles can be tuned to reduce the coupling from its natural value of 3.3% down to 0.9%. A 25 % increase of flux has been measured on all the vertically focused beamlines.

This optimization was obtained after installing a pinhole camera system replacing our previous system which was diffraction limited in the vertical plane. Our new system gives a resolution of 31.2 um. Beam size measurements are useful to study emittance reduction and to perform energy spread measurement (when the source point is at a highly dispersive location) and Touschek lifetime studies.

2 PINHOLE CAMERA PRINCIPLE

2.1 Principle

The photon beam emittance, ε_p, at the source point is the result of a convolution of the electron beam emittance, ε_e, with the photon emittance, ε_r, generated from the single electron emission. Each X-ray from a bending magnet source point passes through the pinhole forming an inverted image of the source on the phosphor screen.

In phase space, and represented at the source point, the pinhole is a straight line (x' = -x/L where L is the distance from the source point to the pinhole) which intersects the photon beam emittance giving the beam profile. In the horizontal plane, the beam sweeps across all angles, limited by the Be window aperture (3mrad in our case). The horizontal profile dimension is then close to the horizontal photon beam size σ_{px} (See fig.1). In the vertical plane, the diffraction ellipse is much larger than that of the electron beam and in this case the intersection with the pinhole acceptance gives a dimension much smaller than the photon beam size σ_{py}. The intersected profile dimension will be closer to the electron beam profile when the electron beam emittance is small or when the pinhole acceptance angle is small (L large). The formula used to extract the real beam size has been described in [1] equation.(3).

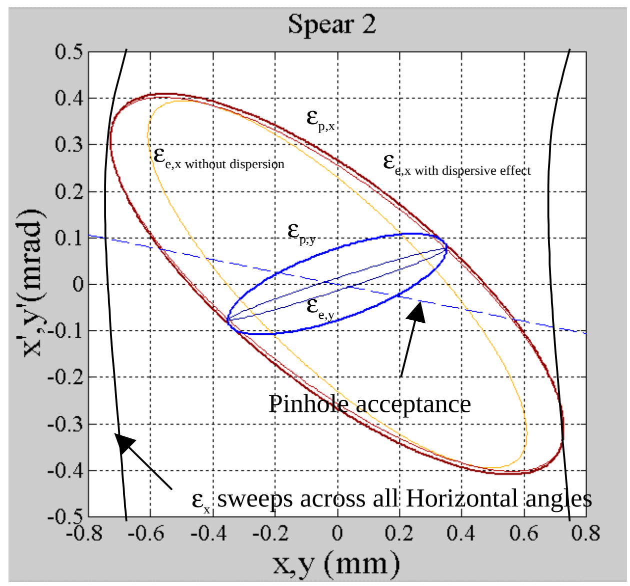

Figure 1: Horizontal and Vertical Emittances in Phase space (vertical for 1% coupling). The 3 horizontal ellipses correspond to electron emittance ε_e, electron emittance including dispersive term $\varepsilon_{e,d}$, ε_p photon beam emittance. The 2 vertical emittances are electron emittance ε_e and the photon beam emittance ε_p

3 HARDWARE

3.1 Pinhole:

A rectangular pinhole was made from 2 pairs of tantalum (Ta) blades 3.2 mm thick. A rake angle of a few degrees was imposed on the surface of the polished blades to minimize undesired reflections. The defining vertical aperture blades are fixed to a copper plate (6.3 mm thick) which absorbs most of the radiation except that going through a 2mm diameter tapered hole. The defining horizontal aperture blades are held by an L- shaped copper plate attached to the back of the absorber plate. The incident 87.5 W per horizontal mrad is absorbed by a water cooled copper plate.

The horizontal slit is 30 um wide and the vertical is 25 um. These were adjusted using an optical (x100) magnifier and the values were confirmed by measuring diffraction patterns obtained when illuminating the pinhole with a HeNe laser.

The pinhole is installed at D1 = 10 m from the source point and its vertical position is controlled using a stepper motor. It was positioned to maximize the flux on the detector.

3.2 *Detector:*

The detector is located at D2 = 5.87 m away from the pinhole giving a factor 1/1.7 demagnification of the beam size. Only a very small space could be devoted to this detector on BL2. The whole detector (a YAG phosphor screen, a Si mirror, a magnifying lens and a CCD camera) is confined in a (25mm x 215 mm x 250 mm) tank

- The CCD camera integrates for a few ms
- The Si mirror is 6.35 mm thick with un-coated Al
- The magnifying lenses (x1, x3, x5) Nikon have numerical apertures respectively of 0.03,0.09, 0.13

A 3D stage provides the position control on the lens + camera system.

- CCD camera Pulnix TM745.

The shutter speed and the integration time of the Pulnix CCD camera are controlled by the Spiricon unit. The digitization is done with the Spiricon. The 480 x 512 pixel picture files are transferred to a PC via GPIB and are then analyzed with Matlab routines.

Integrations over 10 frames were used, given the low flux on our detector.

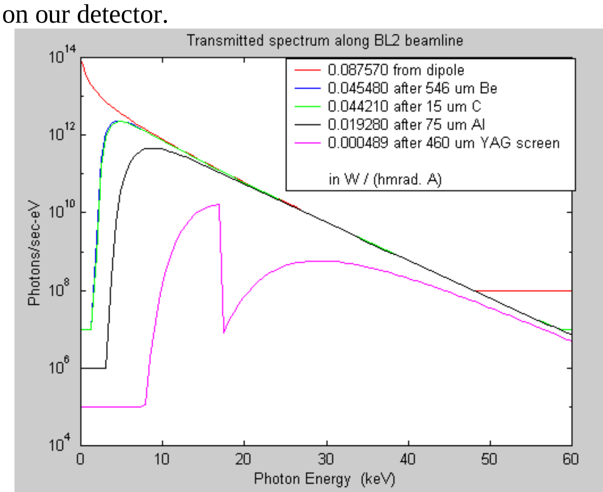

Figure 2: Spectral photon flux along the beamline.

3.3 *Software*

The analysis code is a Matlab translation of a fortran routine developed at NSLS [1]. In order to correctly derive the emittance of the beam from the intensity profile measured with the CCD camera, both the resolution function of the set-up and the diffraction effect of the pinhole must be removed by deconvolution.

- Diffraction from emission from single electron

Photon beam emittance generated by single electron emission is approximated by an upright ellipse with size and divergence given by :

$$\sigma_r' = \frac{0.289}{E(\mathrm{GeV})}\left(\frac{\omega_c}{\omega}\right)^{0.425} \quad \text{and} \quad \sigma_r\sigma_r' = \frac{\lambda}{4\pi}$$

The deconvolution of the photon beam emittance by the diffraction emittance giving the electron beam emittance has been described extensively in [1,2].

- Fraunhoffer diffraction

Even if the pinhole dimension is large (25um) w.r.t the wavelengths of interest (8keV), the Fraunhoffer diffraction effect from the pinhole is important. The intensity I is computed from the amplitude function u using

$$u = \int_{\text{aperture}} \exp\left(i\frac{2\pi}{\lambda}\left(\frac{x_0^2}{D_1} + \frac{(x-x_0)^2}{D_2}\right)\right) dx_0 \quad \text{and } I = uu^*.$$

x^2 and λD are of the same order for 8keV beams so the phase terms $\frac{x^2}{\lambda D}$ are important.

For our parameters (D1 = 10m, D2 = 5.87m, λ=1.55Å), the rms value of the gaussian fit to the diffraction image is 13.4um (or 31.2 um FWHM). The optimal pinhole size for our system is 35 um.

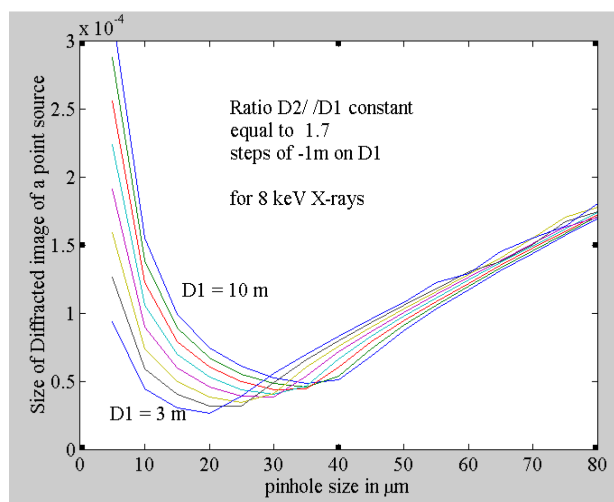

Figure 3: Optimal pinhole size for a fixed ratio D1 / D2 with D1 source to pinhole, D2 pinhole to detector.

- Resolution of detector

When inserting an infinitely narrow slit (ideally Dirac) in the X-ray beam, the image obtained still has a finite size given by the graininess of the phosphor screen and the pixel size of the CCD cells.

Deconvolutions by the resolution function and by the diffraction function are done in spatial Fourier space. For our system, the numerical noise generated by the FFT is equivalent to the detector resolution. Accordingly, our measurement analysis only includes the deconvolution by the Fraunhoffer function.

4 OPTIMIZATION OF SYSTEM

4.1 Low flux

To better understand the source of a very low power density on our system, computation of the spectral power transmission along the beamline was done (fig.2).

X-rays pass through a 550 um Be window, 15 um C filter and 75 um Al foils. The attenuation due to the presence of He in the beamline vessel from the Be window to the detector is negligible above 8 keV.

4.1 Comparison with NSLS system

The Spear system is very similar to the NSLS system, but the difference in flux is as large as a factor of 17. This large factor comes from

- A factor of 1.7 from the small Pinhole aperture
- A factor of 1.77 from the longer source to pinhole distance
- A factor of 2.5 from the electron beam current
- A factor of 2.25 from the attenuation through filters

The 75 um Al foils will be replaced by one 25 um thick. The presence of an Al foil is mandatory for isolating the He tank from air but is primarily used to filter out the low frequencies to avoid chromatic aberrations.

5 MEASUREMENTS

The calibration of the system camera + lens was done using calibrated grids (2.54 um/ line spacing) and was in good agreement with the CCD cell dimensions of the Pulnix camera.

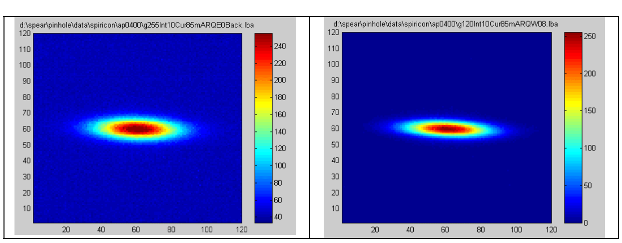

Figure 4: Reduction of vertical emittance.

Measurements were performed to minimize the vertical beam size using the two families of skew quadrupoles. The beam sizes are given in micrometer after deconvolving by the diffraction functions.

Table 1: Measurements

	H	V	V (after correction)
σ (um)	722	199	145
ε (nm)	140	4.68	1.29
Coupling(%)	100	3.3	0.9

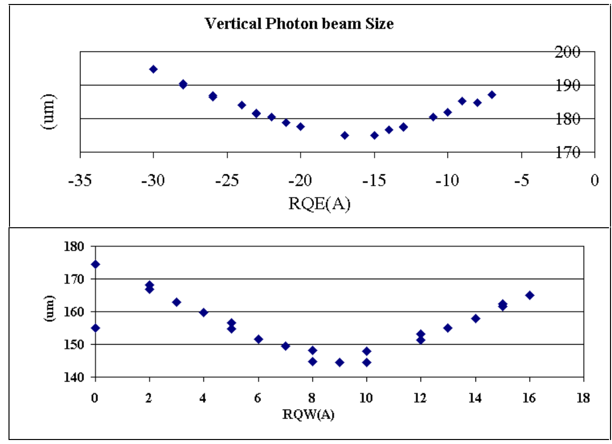

Figure 5: rms of gaussian fits after deconvolution by diffraction function, while scanning the two families of skew quadrupoles

6 CONCLUSION

A smaller diffraction effect could be obtained by moving the pinhole upstream, at 7m from the source point for instance. This will increase the flux through the pinhole, without changing too dramatically the pinhole acceptance and will also improve the resolution of the system.

In a future design, the source point will be at an α_y>0 location such that the beam is focusing in the vertical plane. This will change advantageously the orientation of the ellipse with respect to the pinhole acceptance.

Other measurements are currently performed to measure energy spread vs increasing single bunch current and to study Touschek lifetime.

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