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VERTICAL PHASE SPACE MEASUREMENT PROGRESS AT CANADIAN LIGHT SOURCE*

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Abstract

A key feature of third-generation light sources is their small vertical opening angle, which is difficult to measure experimentally. To reconstruct the vertical phase space, one can scan the beam's position using X-ray synchrotron radiation (XSR) and a pinhole camera and scan the vertical beam size. The XSR diagnostic beamline, operational in the wavelength region of λ = 0.05 - 0.15 nm, in Canadian Light Source (CLS) is qualified to measure the beam position with X-ray radiation. Vertical iterations of 100 µm were executed to the beam's original orbit and the image position was scanned through the pinhole camera. The outcomes of this experiment are: 1) the vertical beam positions that are monitored by BPMs positioned in the Double Bend Achromat (DBA) lattice in CLS on both sides of the X-ray's source point, 2) the X-ray image of the beam that is projected through the pinhole and converted to visible light to be captured on the CCD camera. The bumps were simulated using Matlab Middle Layer (MML) for Accelerator control systems in MATLAB to get an insight of the source point's position in the XSR's bending magnet.

INTRODUCTION

Electron beam emittance ϵ describes the quality of synchrotron radiation sources, and is determined by the magnetic lattice designs in the accelerator storage ring. The emittance is an invariant quantity with respect to the position of the beam along the orbit. By knowing the beta functions β, transverse particle beam size σ, coupling and energy dispersion η, we are able to calculate transverse emittance $\epsilon_{x,y}$ in the machine. Determining the electron beam size using the synchrotron radiation pinhole imaging system is the aim of this studies. Diffraction effects of the photon beam should be accounted for when distinguishing the electron beam from the synchrotron beam image [1,2]. As emittance cannot be directly measured one has to develop techniques to measure the transverse beam size and electron beam divergence in order to reconstruct the phase space. A practical definition of the emittance of the beam is assigning a standard deviation to the statistical distribution of electrons within the enveloping function containing the majority (85 - 95%) of the particles. For the vertical beam emittance, in most of storage rings there is negligibly small dispersion $\eta_y \sim 0$ only anomalous vertical dispersion from passing with very small offsets through quadrupole magnets, it seems like the vertical emittance should also vanish but due to the transverse recoil of the radiated photon's momentum within a finite angle $\frac{1}{\gamma}$, there is a small natural vertical emittance present. The vertical equilibrium emittance is very small 10^{-13} rad.m adding the misalignment of the magnets, coupling is considered to be the dominant effect, and $\epsilon_y \leq 0.01\epsilon_x$. The beam size and beam divergence are given by

$$\sigma_x = \sqrt{\epsilon_x\beta_x + \eta^2\delta^2} \qquad \sigma_y = \sqrt{\epsilon_y\beta_y}, \tag{1}$$

$$\sigma'_x = \sqrt{\epsilon_x\gamma_x + \eta'^2\delta^2} \qquad \sigma'_y = \sqrt{\epsilon_y\gamma}. \tag{2}$$

The η is the periodic dispersion function and $\delta = \frac{\delta E}{E_0}$ is the energy spread. If we ignore diffraction, the photon source parameters in transverse phase space are equal to those of the electron beam, however, the total beam width or height is defined by the contribution of the betatron phase space $\sigma_{\beta,x,y}$ and the energy phase space $\sigma_{\eta,x,y}$. If the diffraction contribution is in the limits of $\epsilon_{x,y} \leq \frac{\lambda}{4\pi}$ the beam energy phase space expands, the beam size is modified to

$$\sigma^2_{ph,x,y} = \sigma^2_{tot,x,y} + \frac{1}{2}\sigma^2_r, \tag{3}$$

$$\sigma'^2_{ph,x,y} = \sigma'^2_{tot,x,y} + \frac{1}{2}\sigma'^2_r. \tag{4}$$

For radiation wavelength λ, the diffraction limited, radial photon source parameters are

$$\sigma_r = \frac{1}{2}\sqrt{\lambda L} \qquad \sigma'_r = \frac{L}{\lambda}, \tag{5}$$

the length L is proportional to the apparent disk diameter from which the photon beam diverges, making L the path along which the particles travel for the corresponding divergence [3]. Here we present our work in progress of the experiment and analysis for measuring the beam phase space at XSR beamline in CLS.

VERTICAL PHASE SPACE RECONSTRUCTION

To reconstruct the vertical phase space following work of [4], a pinhole camera was needed to scan the beam, using the X-ray synchrotron radiation (XSR) beamline [5,6] in CLS we used corrector magnets in CLS lattice made of 12 identical double-bend achromats (DBA) cells, to bump the electron beam by 100 µm iterations and scan the pinhole. Figure 1 shows the average vertical beam profile position of the beam at XSR, and Fig. 2 shows the linear regression fit of the XSR beam profile position data points with respect to

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the beam positions measured in the lattice's Beam position Monitor device named "BPM09". The measured beam size is the projection onto x-space of the line of the pinhole through the emittance phase ellipse in σ_x-σ'_x [1]. If the phase space is tilted the width will be smaller. The simulation shows the position of the source point depends on which corrector sets are chosen. To make a truly parallel bump in the DBA sector and to be able to calculate the source point's actual position, critical in reconstructing the vertical phase space, a particular set of steering magnets should be chosen.

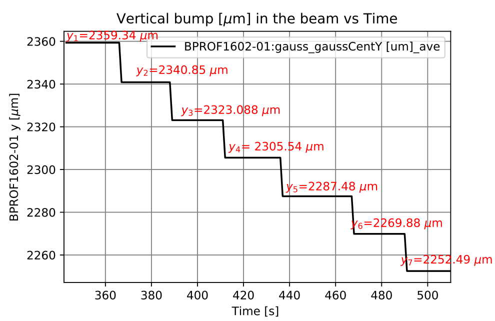

Figure 1: The vertical beam profile bumps recorded in XSR beamline at CLS. The Gaussian fit of the beam center recorded by was saved by EPICS and the beam profile in the pinhole.

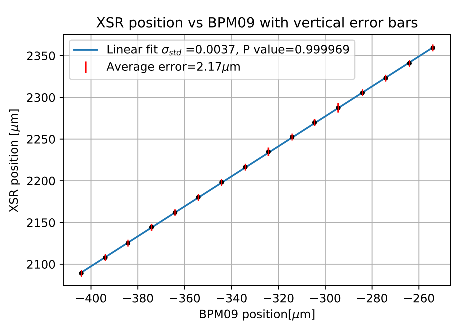

Figure 2: The fitted linear relation of the beam profile position with respect to the beam position in BPM09.

ANALYSIS

The electron beam was bumped parallel using corrector magnets in XSR beamline at CLS. Following the work of scholars if the beam is scanned vertically we should be able to scan the different angles in the beam, The photon phase space density distribution takes a Gaussian form

$$\rho(y_i) = \frac{1}{\sqrt{2\pi}\sigma_{eff}} e^{-y_i^2/2\sigma_{eff}^2}. \tag{6}$$

The point spread function (PSF): σ^{psf} of the pinhole camera divided by magnification factor $M = 1.376$ should be subtracted from the measured beam size in quadrature [5]

$$\sigma^{psf} = 15.5 \text{ m}. \tag{7}$$

To get an insight of the source point's position in the XSR's bending magnet using the MATLAB AT, and choosing all of the corrector magnets in CLS lattice in MML toolbox (Fig. 3). The source point's position is in the 4.0° inside the entrance of the second dipole which has a total bending angle of 15.0°. The beam's position in the XSR's bending magnet calculated by the MATLAB AT shows (Fig. 4) that the source point's position is dependent on the chosen corrector sets. A model for correcting the electron beam orbit is being developed to simulate the orbit correction in the machine to help with the predictions of the orbit positions.

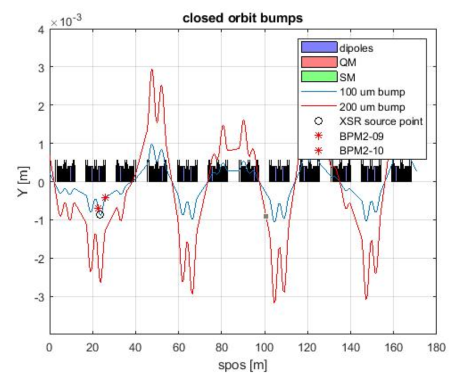

Figure 3: Two 100 μm bumps using all of the vertical correctors simulated by Matlab Middle Layer (MML) toolbox. The BPMs and the source point position in XSR beamline are shown in the figure along the magnet structure.

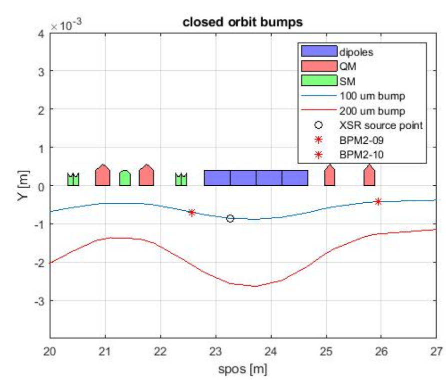

Figure 4: The source point vertical position in XSR beamline with respect to the beam bumps.

The response matrix between corrector magnets and BPMs of the lattice in both vertical and horizontal plane with AT [7, 8], using `ohmienvelope`. An illustration of the response matrix can be seen in Fig. 5 by AT command `demohmienvelope`. Using the 6×6 response matrix [6] M_{resp} between changes in Correctors (steering magnets) strength: $\theta_{x,y}$, and electron orbit's perturbations x, y:

$$\begin{pmatrix} x \\ y \end{pmatrix} = M_{resp} \begin{pmatrix} \theta_x \\ \theta_y \end{pmatrix}. \tag{8}$$

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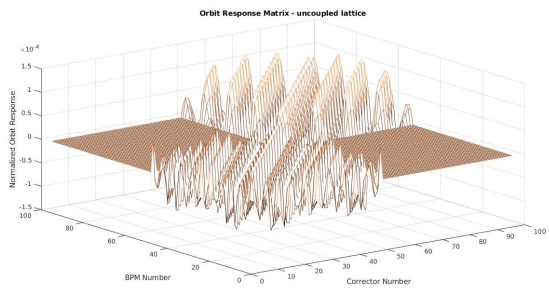

Figure 5: The demo of response matrix for the corrector magnets, by calculating the Ohmi envelope matrix using Accelerator Toolbox, with alterations for CLS lattice illustrated by `ohmienvelopedemo`.

CONCLUSION AND FUTURE WORK

The experiment controlled the positions in BPMs of the lattice while the simulations suggests that the position and angle of the XSR's source point (Table 1) were not controlled. The response matrix would be used to choose a magnet set in order to make a parallel bump in the source point. The results of this experiment on CLS (Fig. 6) contributes to the development of CLS 2.0 (Fig. 7) ring design, a fourth generation light source with multi-bend achromat (MBA) lattice design with a beam size many times smaller than CLS. Our future work will be to continue with the analysis of this experiment [9], to consider the coupling of the horizontal axis to the vertical beam size in Eqs. (1) and (2), and to measure the very small electron beam size in future CLS 2.0, an x-ray interferometry measurement has been proposed, and an experiment to measure the beam's effective coherence length in SM beamline at CLS has been proposed which will help with developing techniques to conduct measurements in CLS 2.0.

Table 1: XSR Source Point Parameters

Parameter	Value	Parameter	Value
α_x	0.50	α_y	−3.12
β_x	0.75 m	β_y	27.03 m
η_x	0.127 m	η_x'	−0.152

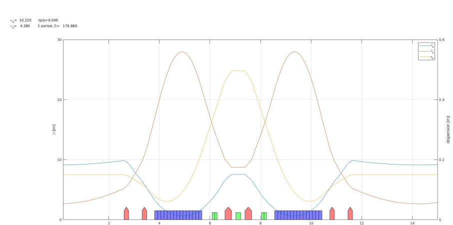

Figure 6: Optical functions at CLS using Accelerator Toolbox in MATLAB.

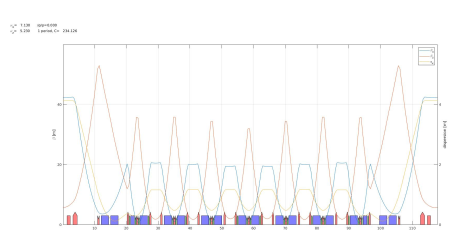

Figure 7: Optical functions at CLS 2.0 using Accelerator Toolbox in MATLAB.

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REFERENCES

[1] H. Wiedemann, *Particle Accelerator Physics*, Switzerland: Springer International Publishing, 2007.

[2] J. W. Goodman, *Introduction to fourier optics*, Switzerland: Springer International Publishing, 1996.

[3] I. A. Vartanyants and A. Singer, "Coherence properties of third-generation synchrotron sources and free-electron lasers", *Synchrotron Light Sources and Free-Electron Lasers*, pp. 821–863, 2017. doi:10.1007/978-3-319-04507-8_23-4

[4] A. Ogata, T. Katsura, T. Kawamoto, T. Mitsuhashi, and N. Yamamoto, "Phase Space Profile Measurement Using an X-Ray Pinhole Camera", in *Proc. 13th Particle Accelerator Conf. (PAC'89)*, Chicago, IL, USA, Mar. 1989, pp. 1498–1501. doi:10.1109/PAC.1989.73492

[5] J. C. Bergstrom and J. M. Vogt, "The X-ray diagnostic beamline at the Canadian Light Source", *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 587, pp. 441-457, 2008. doi:10.1016/j.nima.2008.01.080

[6] J. Safranek, "Experimental determination of storage ring optics using orbit response measurements", *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 388, pp. 27–36, Mar. 1997. doi:10.1016/s0168-9002(97)00309-4

[7] A. Terebilo, "Accelerator Modeling with MATLAB Accelerator Toolbox", in *Proc. 19th Particle Accelerator Conf. (PAC'01)*, Chicago, IL, USA, Jun. 2001, paper RPAH314, pp. 3203–3205.

[8] A. Terebilo, J. Corbett, and G. Portmann, "Accelerator Control Middle Layer", in *Proc. 20th Particle Accelerator Conf. (PAC'03)*, Portland, OR, USA, May 2003, paper WPPE020, pp. 2369–2371.

[9] P. Elleaume, C. Fortgang, C. Penel, and E. Tarazona, "Measuring Beam Sizes and Ultra-Small Electron Emittances Using an X-ray Pinhole Camera", *Journal of Synchrotron Radiation*, vol. 2, pp. 209-214, 1995. doi:10.1107/s0909049595008685