UNIVERSITY OF SASKATCHEWAN

Vertical phase space measurement progress at Canadian Light Source

Y. Yousefi Sigari [1] D. Bertwistle[1,2] M. J. Boland [1,2]

[1]University of Saskatchewan [2]Canadian Light Source

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Introduction

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.

Theory

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.

- The beam size and beam divergence are given by

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

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

where η is the periodic dispersion function and $\delta = \frac{\delta E}{E_0}$ is the energy spread.

- 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 [2]

$$\sigma^{psf} = 15.5\mu m \tag{3}$$

Table 1. XSR source point parameters

Parameter	Value	Parameter	Value
α_x	0.50	α_y	-3.12
β_x	0.75m	β_y	27.03m
η_x	0.127m	η'_x	-0.152
δ	0.11%		

- The photon phase space density distribution takes a Gaussian form

$$\rho(y_i) = \frac{1}{\sqrt{2\pi}\sigma_{eff}} e^{-y_i^2/2\sigma_{eff}^2} \tag{4}$$

Experiment

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. To construct the phase space ellipse, the width is scanned with a pinhole camera and projected back to the phase space Fig. 4. Given the limitations in CLS, we bumped the beam instead of moving the pinhole using corrector magnets in XSR beamline as can be seen in Fig. 2

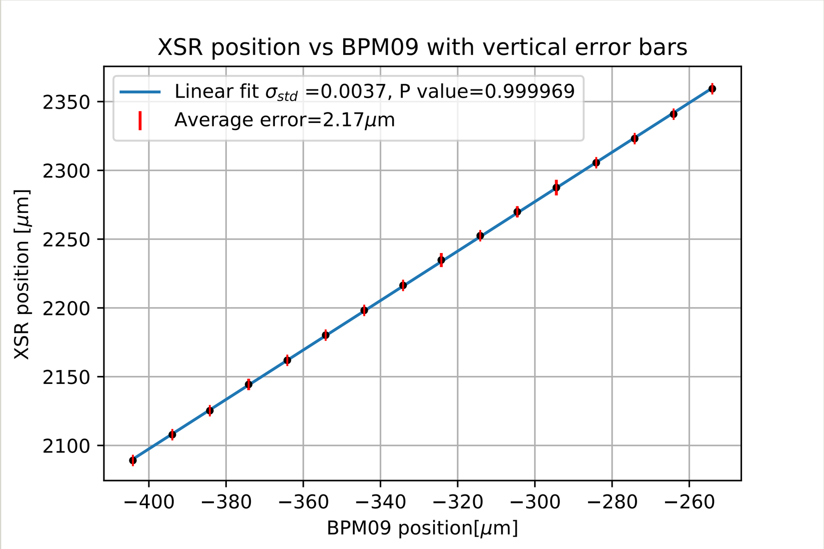

Figure 1. The fitted linear relation of the beam profile's position with respect to the beam's position in BPM09.

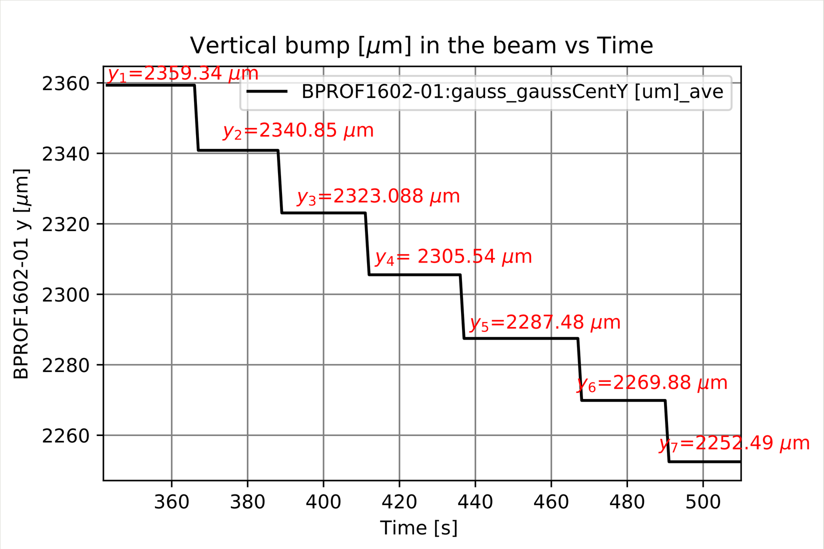

Figure 2. The vertical beam profile's positions recorded in XSR beamline with 100μm iterations.

Simulation

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,

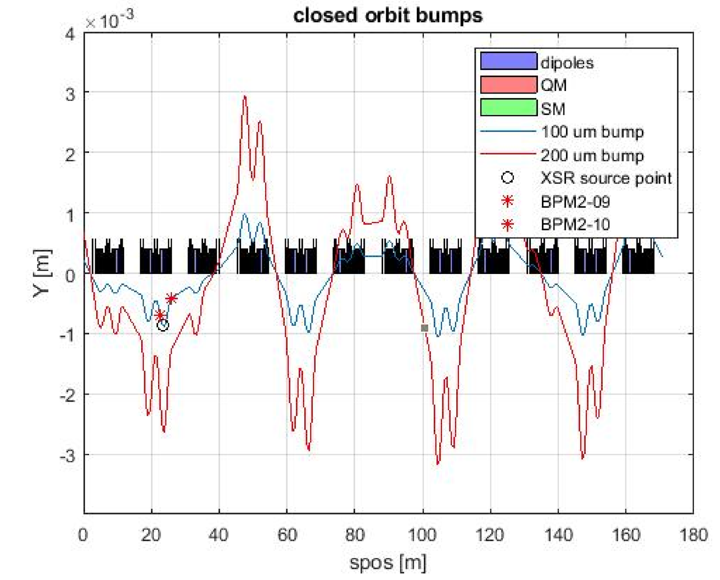

Figure 3. Two 100μm bumps using all of the vertical correctors simulated by Matlab Middle Layer (MML) toolbox. The BPMs and the source point position in XSR beamline along the magnet structure.

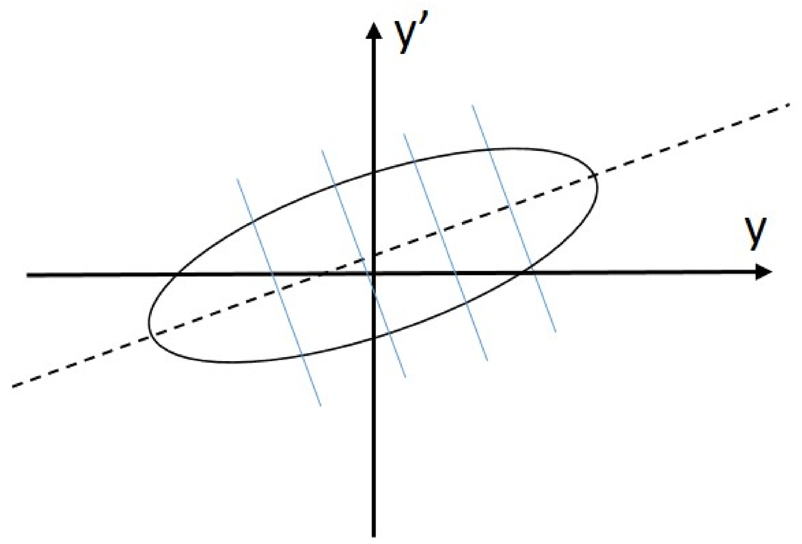

Figure 4. The pinhole camera on each scan can observe one blue line, and by bumping the beam we will be able to reconstruct the phase space.

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 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.

Using the 6×6 response matrix [3] M_{resp} between changes in Correctors (steering magnets) strength: $\theta_{x,y}$, and electron orbit's perturbations: x, y.

$$\begin{pmatrix} x \\ y \end{pmatrix} = M_{resp} \begin{pmatrix} \theta_x \\ \theta_y \end{pmatrix} \tag{5}$$

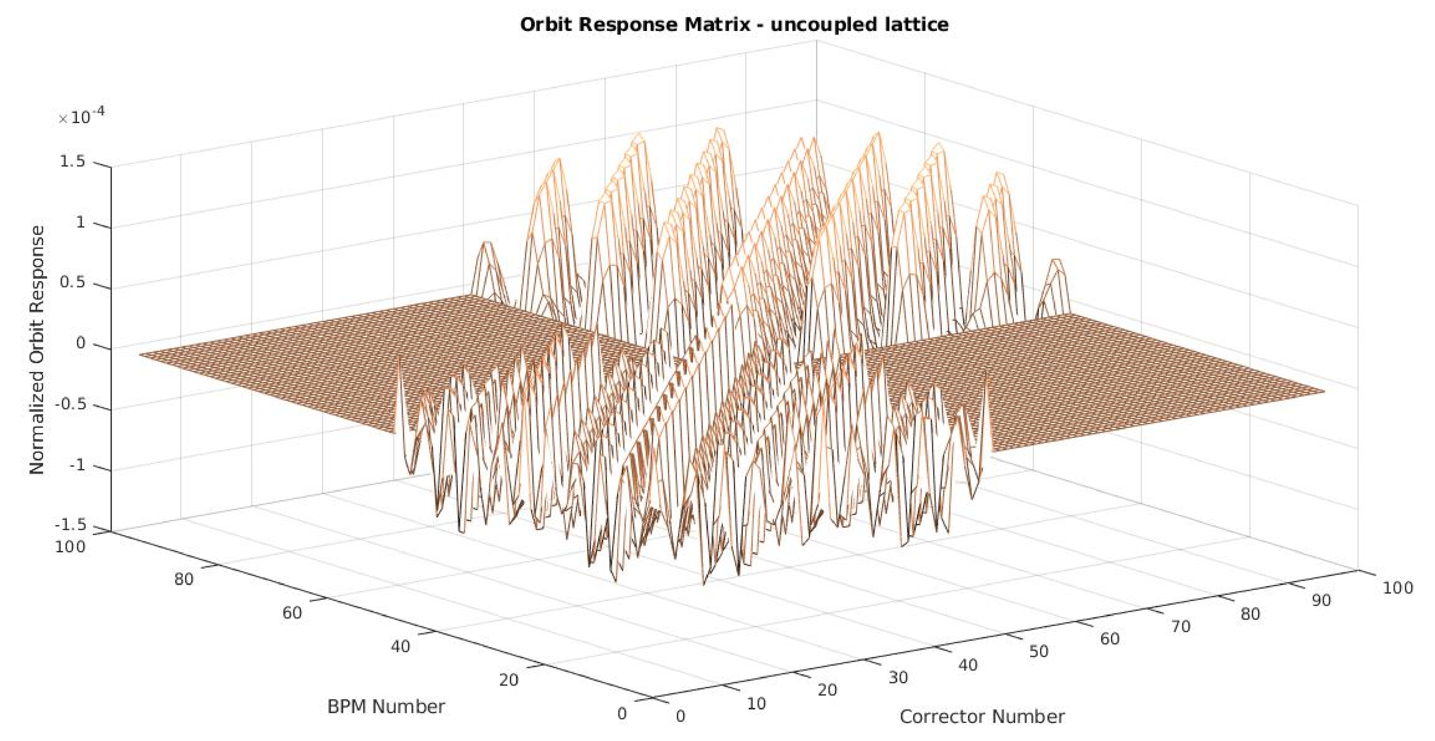

Figure 5. The demo of response matrix for the corrector magnets, by calculating the Ohmi envelope matrix using Accelerator Toolbox, with alterations for CLS lattice illustrated by `ohmienvelopedemo`.

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 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 contributes to the development of CLS 2.0 ring design [4], a fourth generation light source with multi-bend achromat (MBA) lattice design with a beam size many times smaller than CLS.

- Continue with the analysis of this experiment,
- Consider the coupling of the horizontal axis to the vertical beam size in Eq. 1 and Eq. 2. ,
- 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

References

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