ISBN: 978-3-95450-201-1 doi:10.18429/JACoW-IBIC2018-TUOB04

A VERTICAL PHASE SPACE BEAM POSITION AND EMITTANCE MONITOR FOR SYNCHROTRON RADIATION

N. Samadi*, University of Saskatchewan, S7N 5E5 Saskatoon, Canada
L. Dallin, Canadian Light Source, S7N 2V3 Saskatoon, Canada
D. Chapman[1], Canadian Light Source, S7N 2V3 Saskatoon, Canada
[1]also at University of Saskatchewan, S7N 5E5 Saskatoon, Canada

Abstract

We report on a system (ps-BPM) that can measure the electron source position and angular motion at a single location in a synchrotron bend magnet beamline using a combination of a monochromator and an absorber with a K-edge to which the monochromator was tuned in energy. The vertical distribution of the beam was visualized with an imaging detector where horizontally one part of the beam was with the absorber and the other part with no absorber. The small range of angles from the source onto the monochromator crystals creates an energy range that allows part of the beam to be below the K-edge and the other part above. Measurement of the beam vertical location without the absorber and edge vertical location with the absorber gives the source position and angle.

Measurements were made to investigate the possibility of using the ps-BPM to correct experimental imaging data. We have introduced periodic electron beam motion using a correction coil in the storage ring lattice. The measured and predicted motions compared well for two different frequencies.

We then show that measurement of the beam width and edge width gives information about the vertical electron source size and angular distribution.

INTRODUCTION

The stability of the photon beam which is dependent on the stability of the electron source in a synchrotron is critical and essential to the performance of the machine and the beamlines. It is becoming a more important issue as fourth generation storage rings are planned and coming alive and as many other facilities are upgrading their existing rings. The fourth-generation light sources are pushing to very low emittance, so the stability of the electron beam becomes increasingly important as it has a direct effect on the emittance of the machine.

The vertical position of the photon beam at some distance from the source is determined by the vertical position and angle of the electron beam.

We have developed a method to measure the vertical position and angle of the synchrotron electron beam at a single location in a bend magnet beamline at the Canadian Light Source (CLS). The discovery of this system came during an imaging experiment at the Biomedical Imaging and Therapy (BMIT) beamline [3-5] at CLS [1]. Normally to measure the beam angle, two measurements of the beam position at two separated distances from the source are required. This is a difficult task in a beamline due to both lack of space and presence of many beamline optics and components that will interfere with the location and operation of beam position monitors.

The system we have developed relies on measurements of the photon beam profile with and without an absorption edge filter and at the same location in the beamline. In the initial experiments a Bragg type (reflection geometry) Double Crystal Monochromator (DCM)[2] was used to prepare the photon beam at an energy of the filter's absorption edge.

In this paper we present the implementation and results of a system using (1) a single Laue monochromator setup which is compact and is less susceptible to beam power loading and thus energy drift. We have used this system to assess the ability to (2) measure periodic beam motion with the future intent of (3) using these measurements both to show some of the temporal features of the system and to use the beam position and angle measurements to correct experimental imaging data.

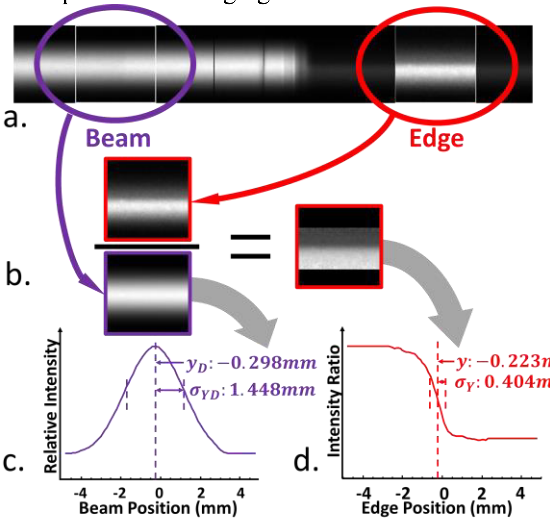

Figure 1: Beam and edge data (a) plus schematic representation of the data analysis steps (b,c,d).

Synchrotron

The vertical photon distribution of a bend magnet or wiggler synchrotron beam can be well fitted with a Gaussian function for photon energies what are well above the critical energy of the device (see Fig. 1c where the Gaussian center and width are shown). In our case, the critical energy of the CLS bend is 7.57keV and the absorption edge of the iodine filter is 33.17keV. Figure

---

* email address Nazanin.Samadi@usask.ca

1a shows the vertical spatial distribution of an imaging beam prepared by a Si (220) DCM at 25m from the source on the left side while the right side shows the effect of an iodine filter. The part in the red circle has been enhanced to show the edge. The edge is found by normalizing the filter side by the beam side. The result is shown in Fig. 1d where the location and Gaussian width is found.

Diffraction, Dispersion and Absorption Edge

The vertical angular distribution of a synchrotron source will present a range of angles onto a crystal monochromator if there are not intervening optics between the source and monochromator as in our case. The small range of angles will prepare a quasi-monochromatic beam that has a range of energies as determined by Bragg's law. Thus, the beam prepared by the monochromator will have a continuous range of energies across the vertical range of angles (energy dispersion) from the source. At some distance, again 25m in our case, this range of angles corresponds to a spatial distribution. Thus, the distance scale in Fig. 1 can also be interpreted as an energy scale. As an example, the energy range contained in our beams (reflection or transmission) is of the order of 50+eV at 33.17keV. This energy range is sufficient to easily cover the energy range of the absorption edge of the iodine filter which was used in these experiments.

THE SYSTEM

The experiments were done at the bend magnet beamline at the BMIT facility at the CLS[3-5]. The beamline was used in "White Beam" mode.

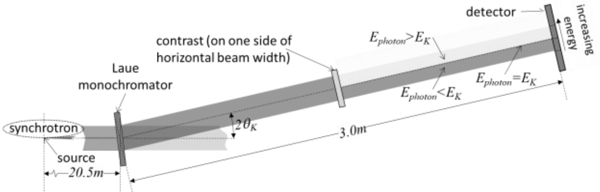

Figure 2: Schematic layout of the ps-BPM system for a single crystal Laue monochromator.

The Laue system is shown schematically in Fig. 2. The crystal was located in the bend magnet imaging hutch approximately 20.5m from the source. The distance from the crystal to the detector is 3m and 23.5 m from the source. A (3, 1, 1) type reflection from a commercially available silicon (5, 1, 1) wafer was used for the Laue monochromator which was tuned to 33.169keV at the absorption K-edge of iodine. The Bragg angle for the lattice planes was 6.55 degrees.

A combination monochromator was prepared for this experiment, one side of this monochromator was the bent Laue for Spectral KES and the other side a flat Laue for beam motion measurements. The Spectral KES is an imaging method using for imaging contrast elements such as iodine in biomedical systems [6, 7]. The simultaneous measurement of imaging data and beam motion data is for using beam motion information to correct the resulting images. The data correction part will be discussed elsewhere. All the beams were intercepted by the same detector (bent Laue for Spectral and flat Laue with and without a contrast filter for beam motion). The advantage of this approach was that the imaging and the correction data were acquired simultaneously. The detector was a Hamamatsu flat-panel with 100 micron pixel size and 30 frames per second acquisition speed.

Each measurement contained data in the form of tiff images in sets of 400. For each measurement a set of 10 flats (images of the beam with no object in the way) and 10 darks (images of detector response with no beam) were also collected to normalize data.

A combination of 0.05 mm copper and 2.5 mm aluminum were used to filter the white beam and prevent thermal loading on the monochromator.

The incident photon beam at the monochromator was around 6 mm high and 178 mm wide.

Two types of data were collected, one during normal operations of the machine and the other one in special request shifts were a known frequency beam motion was introduced in the ring.

While the data was being collected with the ps-BPM system at the beamline, different currents with different frequencies were used in an orbit corrector at location CY1 in Figure 3 to introduce a perturbation in the electron ring. This corrector is the first vertical orbit corrector in cell 3.

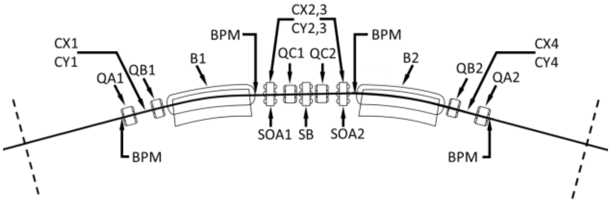

Figure 3: Schematic layout of a cell (one of 12) in the CLS storage ring. CX and CY are orbit correctors, QA, QB, QC are quadrupole magnets, BPMs are electron beam position monitors, SOA, SB are sextupole magnets and Bs are dipole magnets. The dashed lines show the extent of a cell.

The measurements where made using the first bend magnet in cell 5 (B1). The center of the bend magnet beam is 5 degrees into the 15 degree bend provided by the magnet.

These perturbations had frequencies of 5Hz and 10Hz each with currents of 0, 0.12, 0.24 and 0.6A in the orbit corrector.

Both the orbit correction and the transverse feedback system were on during all the measurements and the ring was operating at 250mA current in decay mode.

RESULTS AND DISCUSSION

Measurements where made while the beam was sinusoidally modulated using an orbit corrector while the motion was monitored with the ps-BPM system at the BMIT beamline.

ISBN: 978-3-95450-201-1 doi:10.18429/JACoW-IBIC2018-TUOB04

From the design specification the vertical kick for a corrector is given by

$$kick[\mu rad] \approx 7.637 \times I[A] \tag{1}$$

where I[A] is the current driving the corrector. So, for a 0.12A excitation the kick is 0.916 microradians. The effect of a vertical kick was simulated with DIMAD [8] at the nominal tunes of the CLS lattice. The closed orbit was calculated with a kick of 1.018 microradians at the position of the orbit corrector 1 in cell 3. With this kick the closed orbit at the position of the BMIT bend magnet (B1 in cell 5) beamline is: y = -6.83 micron and y’ = -1.089 microradians for the peak values. For larger kicks the position and angle are assumed to scale with the input current.

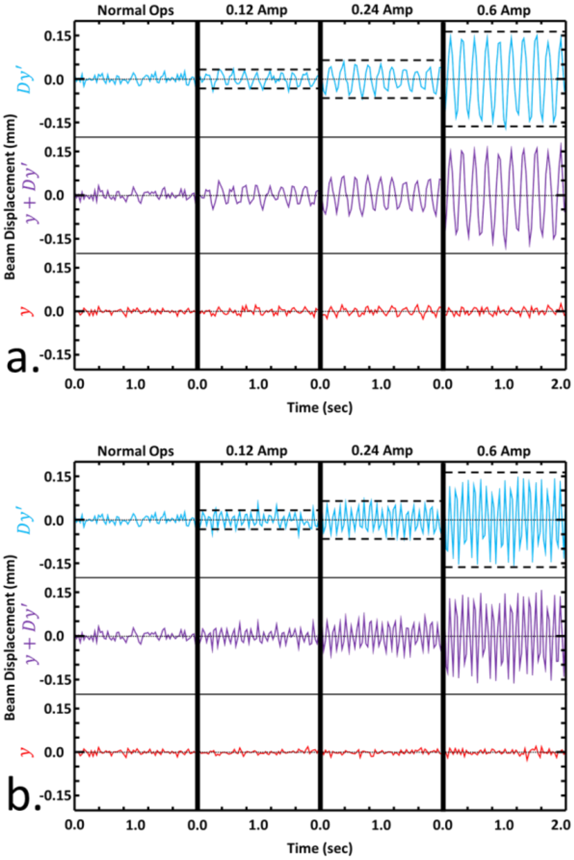

Figure 4: ps-BPM measurements as the orbit corrector current is increased (0, 0.12, 0.24, 0.6A) for 5Hz (Figure a) and 10Hz (Figure b). The dashed black lines indicate the expected peak to peak amplitude of the electron beam motion.

The temporal measured and predicted beam motions are shown in Fig. 4. The measured values are y (red) and y+Dy’ (violet). The derived angular motion Dy’ is shown in blue. Modulation currents of 0, 0.12, 0.24 and 0.6A where used as shown for frequencies of 5Hz (Fig. 4a) and 10Hz (Fig. 4b). The expected amplitude of Dy’ appears as black dashed lines. The expected values of y were too small to mark on the plots.

The measured and expected peak to peak values for the beam motions in Fig. 4 are given in table 1.

There is a good agreement between the predicted and measured values for all currents and frequencies.

Table 1: Measured and Predicted Values (in parentheses) of beam motion for corrector currents and frequencies given in the text and Fig. 4

f (Hz)	I (A)	y(µm)	Dy'(µm)	y'(µrad)	$y + Dy'$(µm)
0	0.0	7.7 ± 2	13.6 ± 2	0.5 ± 0.1	16.2 ± 3
5	0.12	15.6 ± 2 (13.7)	42.5 ± 3 (51.7)	1.6 ± 0.1 (2.2)	57.9 ± 3
10	0.12	9.9 ± 4 (13.7)	51.1 ± 3 (51.7)	2.0 ± 0.1 (2.2)	51.4 ± 3
5	0.24	27.3 ± 2 (27.4)	92.7 ± 3 (103.4)	3.6 ± 0.1 (4.4)	119.9 ± 4
10	0.24	21.3 ± 3 (27.4)	82.9 ± 3 (103.4)	3.2 ± 0.1 (4.4)	104.0 ± 4
5	0.60	43.7 ± 8 (68.3)	255.8 ± 9 (256.2)	9.8 ± 0.3 (10.9)	299.5 ± 5
10	0.60	28.3 ± 6 (68.3)	227.2 ± 7 (256.2)	8.7 ± 0.3 (10.9)	255.1 ± 10

With the similar setup described at the original paper [1] measurements were done while the electron beam size and angular distribution were adjusted using skew quads. The vertical source size and angular size were measured by the system and compared against measurements of the source size made by a pinhole camera at the X-ray Synchrotron Radiation (XSR) diagnostic beamline [9]. The ps-BPM measurements correlate well with beam size measurements at the XSR beamline. Figure 5 shows the measured direct beam width (Fig. 5b) and the edge width (Fig. 5a) from which we can estimate the vertical emittance of the source. The parabolic-type behavior of the measurements indicate that other terms contribute in quadrature to the widths. The results correlate with each other but require further interpretation.

CONCLUSION

A newly developed phase space beam position monitor has been used to measure induced beam motions in a synchrotron source. There is good agreement between the expected motion and those measured by this monitor. The results presented here are the first aspect of using this monitor to correct experimental data for an imaging method, Spectral KES, which is susceptible to the vertical position and angle motion. The fact that these measurements accurately show this motion, gives a good indication that we will be successful in correcting this data.

Also measurements have been made of the widths of the beam and K-edge as skew quads were used to increase the vertical size and angular size of the electron beam. Both size and angular size were shown to increase indication that the vertical emittance can be measured. At this point the sensitivity of these measurements is being assessed as well as other contributors to the measured widths.

Both the data correction and measurements of emittance will be the topics of future papers.

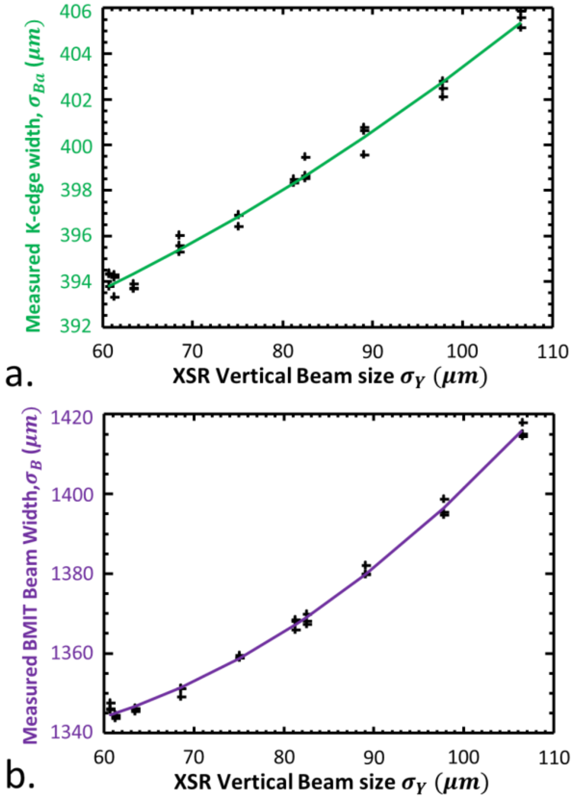

Figure 5: Measured widths of the beam (Figure b) and the K-edge (Figure a) as skew quads are used to increase the vertical beam size. The horizontal axis is the vertical size as measured by XSR beamline.

ACKNOWLEDGMENTS

The authors acknowledge the financial support of Canadian Institutes of Health Research (CIHR) Training Grant –Training in Health Research Using Synchrotron Techniques, Saskatchewan Health Research Foundation Team Grant, Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Grant, the University of Saskatchewan, and Canada Research Chair Program. Research described in this paper was performed at the Canadian Light Source, which is funded by the Canada Foundation for Innovation, NSERC, the National Research Council Canada, CIHR, the Government of Saskatchewan, Western Economic Diversification Canada, and the University of Saskatchewan.

REFERENCES

[1] N. Samadi, B. Bassey, M. Martinson, G. Belev, L. Dallin, M. de Jong*, et al.*, "A phase-space beam position monitor for synchrotron radiation," *J Synchrotron Radiat,* vol. 22, pp. 946-55, Jul 2015.

[2] J. A. Golovchenko, R. A. Levesque, and P. L. Cowan, "X-ray monochromator system for use with synchrotron radiation sources," *Review of Scientific Instruments,* vol. 52, pp. 509-16, 04/ 1981.

[3] T. W. Wysokinski, D. Chapman, G. Adams, M. Renier, P. Suortti, and W. Thomlinson, "Beamlines of the biomedical imaging and therapy facility at the Canadian light source - Part I," *Nuclear Instruments & Methods in Physics Research Section a-Accelerators Spectrometers Detectors and Associated Equipment,* vol. 582, pp. 73-76, Nov 11 2007.

[4] T. W. Wysokinski, D. Chapman, G. Adams, M. Renier, P. Suortti, and W. Thomlinson, "Beamlines of the Biomedical Imaging and Therapy Facility at the Canadian Light Source - Part 2.," *11th International Conference on Synchrotron Radiation Instrumentation (Sri 2012),* vol. 425, 2013.

[5] T. W. Wysokinski, D. Chapman, G. Adams, M. Renier, P. Suortti, and W. Thomlinson, "Beamlines of the biomedical imaging and therapy facility at the Canadian light source - part 3," *Nuclear Instruments & Methods in Physics Research Section a-Accelerators Spectrometers Detectors and Associated Equipment,* vol. 775, pp. 1-4, Mar 1 2015.

[6] Y. Zhu, N. Samadi, M. Martinson, B. Bassey, Z. Wei, G. Belev, *et al.*, "Spectral K-edge subtraction imaging," *Physics in Medicine and Biology,* vol. 59, pp. 2485-2503, 2014.

[7] N. Samadi, M. Martinson, B. Bassey, A. Gomez, G. Belev, and D. Chapman, "An energy dispersive bent Laue monochromator for K-edge subtraction imaging," *AIP Conference Proceedings,* vol. 1741, p. 040004, 2016.

[8] R. V. Servranckx, K. L. Brown, L. Schachinger and D. Douglas, "Users Guide to the Program DIMAD," Stanford Linear Accelarator Laboratory, Stanford Linear Accelarator Laboratory, 1990.

[9] J. C. Bergstrom and J. M. Vogt, "The optical diagnostic beamline at the Canadian Light Source," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment,* vol. 562, pp. 495-512, 6/15/ 2006.