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X-ray Beam Stabilization System Utilizing Diamond Beam Position Monitors

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ABSTRACT

The mechanical, optical, electronic and thermal properties of diamond make it an ideal material to address the x-ray beam monitoring needs of modern synchrotrons. Diamond Beam Position Monitors (DBPMs) have demonstrated to yield position resolutions of 25 nm for stable beams and a have shown linear flux responses of at least 11 orders of magnitude. Readout electronics tailored to suit the performance and integration needs of DBPMs are needed to fully harness the potential of the technology. Sydor Instruments LLC in collaboration with Brookhaven National Laboratory (BNL) has advanced a novel electronic readout system based on the electron Beam Position Monitor (eBPM) readout systems developed for the National Synchrotron Light Source II (NSLSII) storage ring. The developed system, SIEPA3P, is a 4-channel electrometer with an internal power supply, Ethernet based Experimental Physics and Industrial Control System (EPICS) controls and a Control System Studio (CSS) user interface to operate DBPMs. The system has been deployed at the NSLSII CHX beamline for x-ray beam diagnostics and stabilization. The SIEPA3P utilizes a Sydor Instruments' DBPM for beam characterization in conjunction with a horizontal mirror and a Double Crystal Monochromator for x-ray beam stabilization.

DIAMOND BPM OPERATION

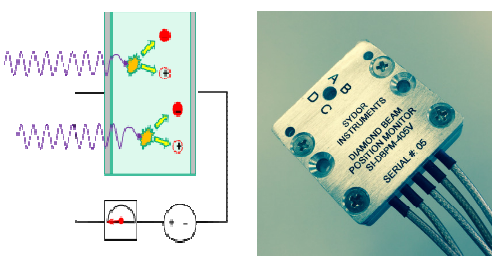
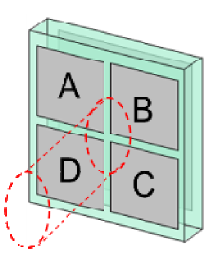


Fig. 1 Electron-hole pair production in CVD diamond (Left). Sydor DBPM (Right).

When x-rays are absorbed by a diamond sensor they produce electron-hole pairs that can be measured by applying a bias across the sensor. The mean ionization energy for an electron-hole pair in electronics grade single crystal diamond is 13.3eV. Diamond has been shown to have a linear response over 10 orders of magnitude, thus the current produced by an x-ray beam on a diamond sensor can be calibrated to obtain the beam flux. In addition, if one of the sides of the sensor contains quadrants then by comparing the ratios of the current collected by each quadrant one can obtain the position of the x-ray beam. The difference over sum algorithms on the bottom right is used to obtain the beam positon based on the quadrant readouts.



$$Y = G_y \frac{(A+D)-(B+C)}{A+B+C+D}$$

$$X = G_x \frac{(A+B)-(C+D)}{A+B+C+D}$$

Fig. 2 Quadrant Diamond BPM (Left). The charge collected by each quadrant is utilized to calculate the x-ray beam position via a difference over sum algorithm (Right)

SIEP-A3P ELECTROMETER

Fig. 3 SIEPA3P bipolar electrometer

The SIEPA3P electrometer has 5 gain stages that allow the measurement of currents from 20pA up to 35mA with a bipolar capability. The digitized currents are obtained via a 10Hz stream or buffered at 10kHz. The currents are digitized either by utilizing an internal clock source (asynchronous mode) or an external clock source (synchronous mode). The synchronous mode is designed to facilitate the integration of the electrometer with the timing protocol of a beamline or synchrotron. In addition the electrometer supplies the bias for the DBPM either by an internal bipolar 45V bias source or by routing and external bias source. For feedback stabilization, the SIEPA3P has 4 analog outputs which are controlled by internal, user configurable PID loops. All controls are implemented by utilizing an EPICS Input Output Controller (IOC) in conjunction with a Control System Studio (CSS) graphical user interface (Figure 4).

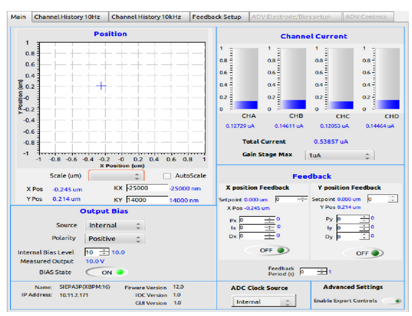


Fig. 4 SIEPA3P Graphical User Interface (GUI)

BEAMLINE TESTING

Beamline testing of the SIEPA3P was performed at NSLSII CHX beamline. The beamline utilizes a Sydor Instruments DBPM for intensity and positon diagnostics close to the sample position. Measurements were performed with a 8.98 keV ~ 10um(v) x 10um(h), monochromatic beam. The beam was centered on the DBPM to characterize the beam motion in the horizontal and vertical axes. The data was acquired at 10Hz. A significant drift in the vertical direction was observed as shown in figure (Figure 5).

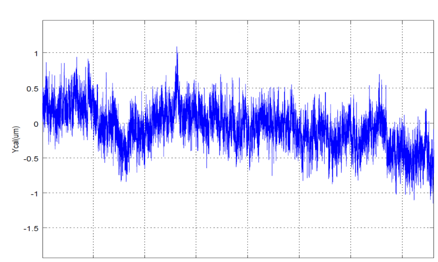


Fig. 5 Vertical x-ray beam motion observed over a 15 minute period

BEAM POSITION STABILIZATION

In order to suppress the vertical x-ray beam drift, the SIEPA3P monitored the beam motion with the installed DBPM and controlled an upstream monochromator. The monochromator was controlled via the SIEPA3P DAC outputs and utilizing the unit's internal, user configurable PID controls loops. Figure 6 shows the effect of the beam stabilization at 1Hz when the feedback was enabled and disabled over a period of approximately 15 minutes.

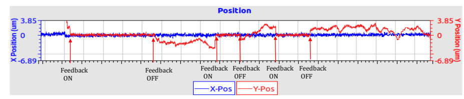


Fig. 6 Vertical x-ray beam motion when the SIEAPA3P feedback was enabled and disabled over a 15 minute period

A closer look into vertical beam stability over a period of 5 minutes showed a significant decrease in beam motion and closer overall beam centering on the DBPM when the SIEPA3P feedback control was enabled. This demonstrated that the SIEAP3P feedback control is effective is suppressing sub-Hertz beam motion (Figure 7).

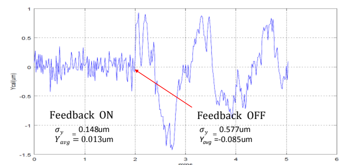


Fig. 7 Vertical beam stability with the SIEPA3P feedback control enabled and then disabled.

FAST BEAM MOTION ANALYSIS

Knowledge of the characteristic beam motion frequencies and their relative contributions provide important information to identify potential sources of beam motion and is crucial to improve beam stability. The SIEPA3P allows users to acquire 10kHz beam motion data for up to 13 seconds for analysis. 13 second-10 kHz vertical beam motion data gathered at the CHX beamline is shown in Figure 8.

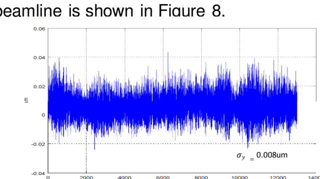


Fig.8 10KHz data of beam vertical motion

A Fast Fourier Transform of the data showed significant beam motion contributions below 100Hz (Figure 9a). The power spectrum of the data (Figure 9b) as well as the relative beam motion contributions at different frequencies (Figure 9c) showed that a principal source of noise occurs around 66Hz. In order to mitigate this noise source, a 100Hz feedback upgrade to the SIEPA3P will be tested in the near future at the CHX beamline.

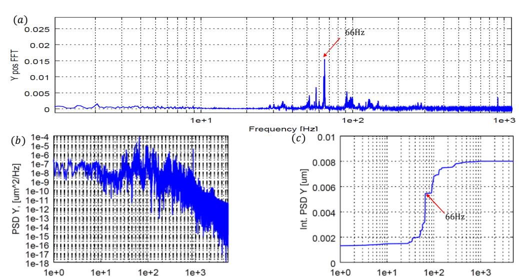


Fig.9 Measured vertical beam motion: (a) Fast Fourier Transform (b) Power spectrum (c) Frequency contribution to vertical beam motion.

ACKNOWLEDGEMENTS

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