RECENT DEVELOPMENTS OF DIAGNOSTICS AT DIAMOND

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Abstract

We are reporting on the integration of photon beam diagnostics with the orbit feedback system. Measurement of the X-ray beam position from ecliptically polarising undulators requires a solution that reliably operates with the changing beam profiles emitted by these devices. Additionally, for operation in low-alpha mode with few ps bunch lengths, we have been evaluating various techniques for the measurement of these short bunch lengths.

INTRODUCTION

Diamond Light Source has grown from its initial set of 7 beamlines in 2007 to now 21 beamlines installed. Established beamlines have increased their requirements for long term stable delivery of X-ray beams, so that the feasibility and best strategy for a feedback on readings from X-ray beam position monitors had to be investigated. The introduction of further ecliptically polarised undulators as insertion devices required improved capability of monitoring the position of the challenging X-ray beam distribution created by these using a fundamentally different principle to blade photoemission monitors.

But not only demands on photon beam position stability have increased, also the requirements for temporal resolution have been increasing to below ps by low-alpha operation of the storage ring optics.

X-RAY BEAM POSITION FEEDBACK

All 14 beamlines with undulators are equipped with tungsten vane X-ray beam position monitors (XBPMs) in their frontends, which have been routinely used to monitor the stability of the beams delivered to the beamlines.

On some particularly sensitive beamlines we are now operating with a slow feedback (settings are applied once per second) that stabilises the X-ray beam in the frontend. This has been shown to benefit critical alignment near the sample over durations of hours and days [1].

In Fig. 1 a record of 6 days of continuous beam delivery is shown. The feedback was operating on the XBPM2 reading only and applying purely angular corrections to the 'golden orbit' settings (which are the demand values for the global fast orbit feedback) by setting the offsets of the upstream and downstream EBPMs with opposite sign. The resultant standard deviation of beam position readings at the controlled XBPM2 is just 64 nm over the whole 6 day period, while at the monitoring XBPM1 it is just slightly more at 188 nm.

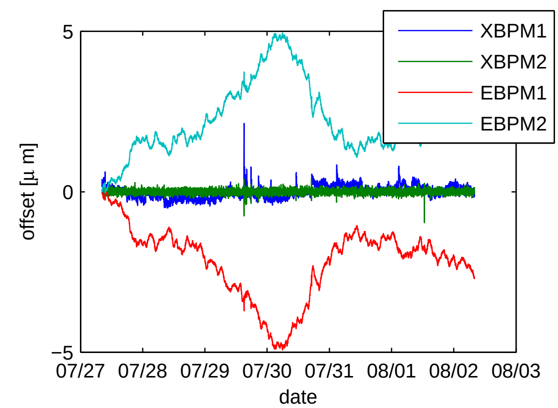

Figure 1: A 6 day record of vertical beam position offsets at two frontend XBPMs and 'golden orbit' offsets set by the slow feedback to keep the beam stable at XBPM2.

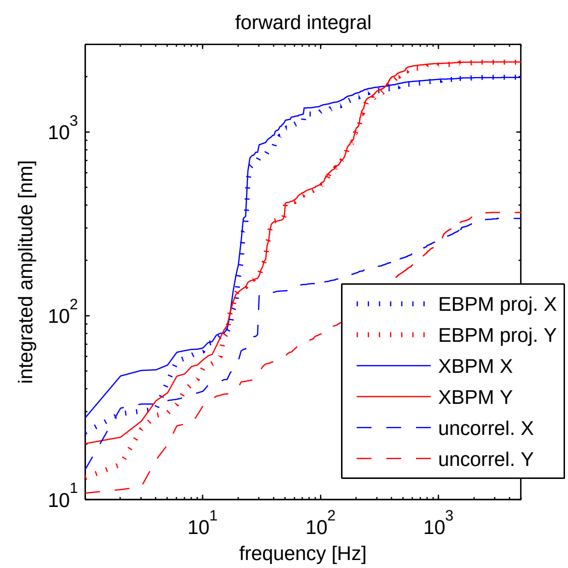

Figure 2: Integrated motion amplitudes of projected EBPM and XBPM positions (at the location of the XBPM), and uncorrelated components.

On the other hand, we have investigated if there would be further benefits from including the position readings from XBPMs with low latency and high bandwidth in the global fast orbit feedback. To this end, we have synchronously recorded fast readings of both EBPMs and XBPMs adjacent to one undulator [2]. We then geometrically projected from the EBPM position what would be expected at the XBPM location and compared that with the recorded XBPM position readings.

The strong correlation can best best be judged by comparing the integrated motion spectra in Fig. 2. When the correlations are calculated over a larger number of samples (10072 or 1 s of readings) it is about 95% in both axes. Using a singular value decomposition we have separated the correlated and uncorrelated components.

It can be seen that the uncorrelated component, which carries the random error from all three instruments involved, is almost one order of magnitude down for most of the frequencies observed. Only at frequencies below 10 Hz is the uncorrelated component closer to the actual amplitude, but then the absolute magnitude is only a few nm up to these frequencies.

The spectral shape of the uncorrelated component carries one interesting point: While the Y component resembles white noise up to the low pass filter in the EBPMs, the X component exhibits one bump at about 30 Hz, which is present in the XBPM but not the projected EBPM reading. Further investigation is required to clarify where this originates from, however, this line adds only 50 nm to the integrated amplitude.

We reason from these long and short term measurements, that while the benefits of a slow feedback on XBPM positions are obvious, there would hardly be any improvement of the short term beam stability or rejection of vibrations if XBPM data were to be included with low latency in the global fast orbit feedback.

APERTURE XBPM

Tungsten vane X-ray Beam Position Monitors (XBPMs) can be designed to perform well for most X-ray beam distributions. However, frequently changing or none-Gaussian beam shapes as created by Elliptically Polarising Undulators (EPUs) produce a wide range of photon distributions that fixed blade monitors are not capable of operating with properly.

An alternative approach adopted at an ESRF beamline is the imaging of scattered photons [3]. A thin scattering foil is placed into the X-ray beam path and a small amount of the total flux is scattered by the foil and these photons are then spatially imaged.

We set out to apply this principle for use in the frontend of an EPU but found that a foil would absorb too much power due to the photon energy range starting as low as 100 eV. Instead, we introduced an aperture with a hole in the centre to pass through the photons used by the beamline, while the outer parts of the distribution are scattered and can be imaged subsequently.

The aperture is formed by a copper wedge with a 10 mm hole in the centre. The wedge is water cooled to dissipate the heat of the absorbed fraction of the X-ray beam. The scattered photons are then imaged using a pinhole onto a fluorescent screen and observed using a camera as shown in the sketch in Fig. 3.

Images acquired by the camera (examples shown in Fig. 4

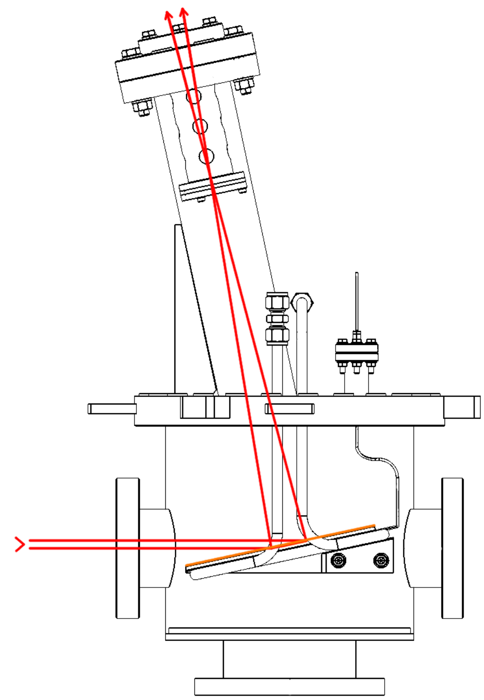

Figure 3: Cut view of the aperture XBPM: The red lines depict the path of X-rays in the outer region of the incoming beam, which are scattered by the surface of the copper aperture

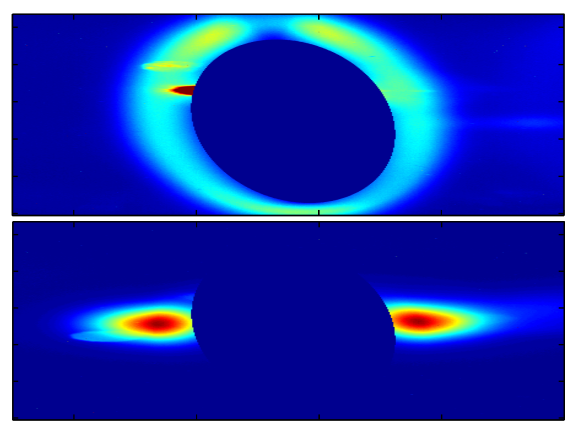

Figure 4: Example images of scattered photons for two different polarisations of the EPU: circular polarisation (top) and horizontal linear polarisation (bottom). Camera images have been processed to remove some artifacts from the area inside the aperture and to remove some of the distortion caused by the imaging geometry.

are then processed to calculate the centre of mass. This has been found to track the beam position linearly over a range of ±0.5 mm [4]. Further work will be required to investigate and remove the cause of artifacts in the image which are thought to be caused by specular reflections of visible light and which lead to a degradation in the position detection.

SHORT BUNCH LENGTH MEASUREMENTS

Low-alpha optics for generation of few ps X-ray pulses to be used in time resolved experiments have been introduced at Diamond [5]. Since at these timescales bunch length measurements using a streak camera are reaching resolution limits we have investigated alternative methods of measuring short light pulses with below ps resolution and for low intensities which are typical in low-alpha operation. The first method is based on power fluctuations of the synchrotron radiation from a single bunch, while the second is using the detection of a multi-photon correlation to infer the bunch length.

Bunch Length from Power Fluctuations

This method has been developed and demonstrated at the APS [6] and is based on the statistical properties of the pulse intensity with a coherence length much smaller than the pulse envelope. We have implemented this method at Diamond using a cooled avalanche photodiode with superior low noise performance.

Furthermore, the measurement requires determination of the statistics (specifically the mean and standard deviation) of the visible light power within a specified bandwidth emitted by a single bunch on every turn and the total measurement time and resolution depends directly on how quickly and precisely these statistics can be gathered. To this end, a data acquisition system capable of capturing the pulse intensity of every turn is the fastest that can be achieved. We have found this is possible with a modern digital oscilloscope which have statistics capabilities implemented in hardware, as well as with a multi channel analyser which is designed for the task of pulse statistics measurement.

Using this configuration, we have been able to measure the statistics of synchrotron light pulses with a relative uncertainty of about 0.2% within 1 s measurement time and have shown that the derived pulse lengths correlate well with streak camera measurements for bunch lengths of 13–16 ps [7]. Future work will extend this method to use operation in low-alpha mode for which an upgrade of the visible light transport line was required in order to increase the intensity at the sensor.

Bunch Length from Multi-Photon Statistics

The major limit of the power fluctuation method is the relatively high intensity of light pulses that is required. To overcome this we have been looking at a different principle which is based on determining the second order correlation function of detecting a two photon-coincidence with two detectors within a given pulse length. This method has been demonstrated for fluorescence measurements [8] but has so far not been applied to synchrotron radiation to our knowledge.

The main advantage of this method is that it requires only very low flux, since individual photons are detected. Furthermore, its resolution is only limited by the step size of an optical delay stage, so that sub-ps resolution requires only trivial mechanics. As a drawback, the measurement time can be quite long since the maximum number of coincidences that can be counted within a given period without pileup is limited to a fraction of the number of light pulses within that period. Since these coincidence counts need then be repeated for many different setting of the delay stage, total measurement periods in the order of hours can result.

We have evaluated this method using a short pulse laser as the source and managed to produce first measurements. Measurements of synchrotron light pulses are planned for the near future.

CONCLUSION

Recent Diagnostics developments at Diamond have been driven by increased demand from beamlines to deliver ultra-stable X-ray beams. To this end we have illustrated the stability that can be achieved using a position feedback based on a front end XBPM and discussed our philosophy of integration with the global fast orbit feedback. We also presented a new method of monitoring the position of X-ray beams from EPUs with their characteristic multitude of beam shapes. Finally, we addressed the need for measuring bunch lengths and synchrotron light pulses with sub-ps resolution by presenting two alternative approaches to the traditional streak camera method.

REFERENCES

[1] C. Bloomer, G. Rehm, C. Thomas, **WEPEB047**, in *Proceedings of IPAC2010*

[2] G. Rehm, M.G. Abbott, C. Bloomer, I. Uzun, **MOPD78** , in *Proceedings of DIPAC2011*

[3] R.G. van Silfhout, S. Manolopoulos, N.R. Kyele, and K. Decanniere, *Sensors and Actuators A: Physical*, 133(1):82 – 87, 2007

[4] C. Bloomer, G. Rehm, C. Thomas, **MOOB01**, in *Proceedings of DIPAC2011*

[5] I.P.S. Martin, G. Rehm, C.Thomas, R. Bartolini, Phys.Rev. ST Accel. Beams, **14** (2011), 040705

[6] F. Sannibale, G. V. Stupakov, M. S. Zolotorev, D. Filippetto, and L. Jägerhofer, Phys.Rev. ST Accel. Beams **12** (2009), 032801

[7] C.A. Thomas , I. Martin, G. Rehm, **MOPD32**, in *Proceedings of DIPAC2011*

[8] Y. Li, M. Baba, M. Matsuoka, Physical Review A, 55(4), 3177-3183, (1997)