NUMERICAL AND EXPERIMENTAL INVESTIGATION OF THE CONTAMINATION OF X-RAY BEAM POSITION MONITORS BY BENDING MAGNET EDGE RADIATION

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Abstract

The details of an investigation into bending magnet edge radiation at Diamond are discussed, reviewing the effects of this radiation on X-ray Beam Position Monitoring (XBPM) equipment. For some time it has been recognized that there are difficulties using XBPMs for determining the centre of mass position of an undulator beam due to contamination from bending magnet radiation. While the geometry of the XBPM blades is designed to help reduce background dipole interference, this radiation is known to account for approximately 1% of the signal received, skewing the calculated beam position by several micrometres. We made detailed models of the bending magnet edge radiation using the SRW program and used MatLab to analyse the data. We present this model and compare our prediction to experimental results obtained at Diamond.

INTRODUCTION

Diamond Light Source (DLS) is a third generation synchrotron based in Oxfordshire, UK, and has been operational since January 2007. Synchrotron light sources have experimented with XBPMs for several years in order to monitor beam position and stability [1] and to provide X-ray beam based feedback [2]. XBPMs are becoming an integral part of new light sources.

At Diamond most front ends have two tungsten blade photo-emission XBPMs installed, based on a design by K. Holldack and manufactured by FMB GmbH. Four tungsten blades are mounted on actively cooled copper blocks in order to transfer away heat generated by the synchrotron radiation, and the blade currents are amplified by ENZ 4-Channel Low-Current Monitors (LoCuMs).

The blade geometry is designed such that the blades only scrape the edge of the central radiation cone, leaving the centre undisturbed (Fig. 1). Beam position can be determined using a simple asymmetry calculation from the currents of the four blades, A, B, C and D: vertical displacement = (A+B-C-D)/(A+B+C+D). A calibration table is created in order to convert this current ratio into actual beam position. Further details regarding the design and calibration of these devices are treated in detail elsewhere [3] [4].

Care is taken to geometrically arrange the blades to reduce the impact of dipole radiation. However, photons from the nearest bending magnet are known to skew the recorded beam position since the blades detect both undulator radiation and dipole radiation alike. Treatment of this dipole radiation differs between light sources, some choosing to subtract a measured 'background count' from the final value, others ignoring it as it accounts for so little of the recorded intensity.

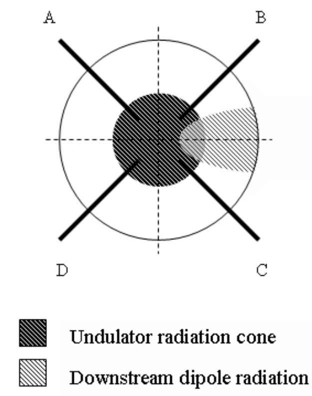

Figure 1: Looking downstream at XBPM blades and aperture from an undulator.

Figure 2 shows a schematic of a typical undulator straight and front end. It can be seen that the dipoles at either end of the insertion device (ID) straight produce synchrotron radiation that propagates through the front end aperture and affect the XBPM blades. It can be seen from simple geometry that the upstream dipole contributes 5% of the radiation that the downstream dipole contributes due to being located further away from the detector. This number is also what is found experimentally. For the purposes of this paper the upstream dipole is considered to have negligible effect on the XBPMs.

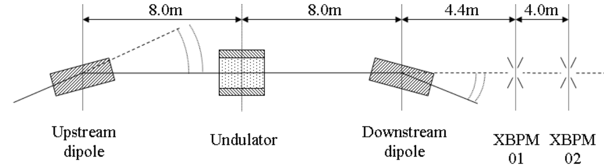

Figure 2: Schematic of Diamond ID straight and Front End.

MODEL OF THE XBPM

At Diamond we are attempting to model this dipole radiation and the effect it has on the monitors so that we can best assess how to deal with the problem. Using SRW 3.90 [5] undulator radiation can be modelled and calculated at different gap sizes and distances from the source. It is also possible to calculate synchrotron radiation from dipole sources.

The data is imported to MatLab where multi-dimensional matrices are created, giving beam shape as a function of energy and undulator gap. The response of the photodetector blades depends on the photoionization rates of tungsten and on the energy deposited into the blade. There is much research on the photoionization cross section of tungsten [6], however less is available on how higher energy photons may liberate multiple electrons from a tungsten surface. To establish this, comparisons have to be made between experimental data obtained at Diamond and theoretical data.

MatLab's imaging abilities allows a 'mask' of the blades to be constructed, and thus a simulation of the intensity spectrum of light impacting on the blade surface. This spectrum can be weighted by the spectral efficiency of tungsten in order to model what the detected blade current should be. Through manipulation of the data it is possible to change the simulated viewing position, or source point, as well as simulate different beam shapes, XBPM designs or even the effect obstructions to the beam can have on the XBPMs. Beam movements can be simulated by shifting the matrix in 2 dimensions (Fig. 3).

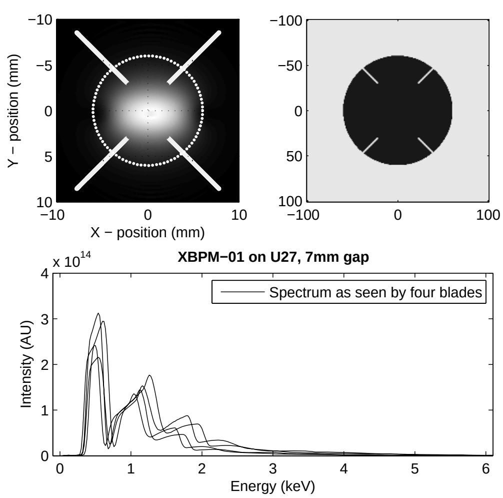

Figure 3: MatLab simulation of off centre radiation spectra striking four XBPM blades with 300µm beam displacement.

PSEUDO IMAGE FROM XBPM SCAN

Each of the ID XBPMs are mounted on stepper motors capable of micron precision movements, able to move the device both horizontally (x-axis) and vertically (y-axis). These motors are used to centre the XBPM on the beam and for calibration, however they are also capable of making 'scans' of the edges of the beam. By moving the XBPMs back and forth across the aperture it is possible to build up an image of the beam intensity by recording the individual blade currents. This has the advantage over inserting a fluorescent screen into the beam in that it can be done without interrupting user beam-time.

Figure 4 depicts an image produced by this method using XBPM-02. Predominantly visible is a ring from harmonics from a HU64.

The blades only 'see' low energy photons. Weighting theoretical spectra by tungsten photoionization rates strongly suggests that a low energy, $<$1keV, spectral ring at 300µRad is predominantly responsible. The first harmonic, a high intensity central cone, is not visible since it is not possible to move the XBPM blades directly into this without damaging them. Also visible is the shadow in the beam created by the blades of XBPM-01.

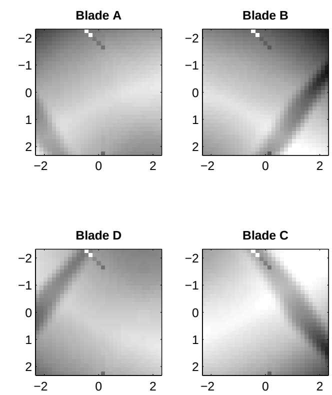

Figure 4: Experimental scans of a circularly polarized HU64 beam at Diamond using XBPM-02. High blade currents are represented by light areas (distances are in mm).

In this case an obstruction to the beam (the four upsteam monitor blades) can clearly be seen, and this is a useful technique to check the positioning of the upstream monitor. However, by using the upstream monitor it is possible to image a wide aperture without any obstruction, and see a broad cross section of the beam. The rest of the discussion focuses on using the upstream monitor to retrieve beam information and comparing this with theoretical data.

EDGE RADIATION

Opening the gap on an ID allows a measurement of the 'background' dipole radiation to be made. Taking the example of the beamline I24, with a U21 planar undulator, the measured dipole contribution to the XBPM blade photocurrent is 3% of the total measured at minimum gap on XBPM-01. This corresponds to up 20µm beam displacement. Our current model predicts a 50µm beam displacement, which is in relatively good agreement with the measurements, however, a finer model of the blade photocurrents should provide more accurate results.

Figure 5 shows a comparison between the model and experimental data taken on I24 at Diamond. As the ID gap increases the bending magnet radiation becomes more dominant, skewing the measured beam position.

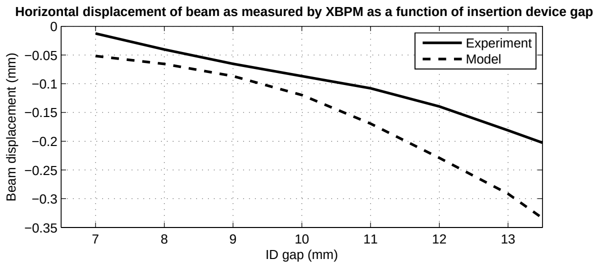

Figure 5: Graph depicting the displacement of the beam as measured by an XBPM as a function of ID gap.

Further investigations of the model have been made using the U21 at Diamond. Scans of the beam at various gaps have been made, and compared to the simulated scan images produced by SRW/MatLab. Some of these are presented in figures 6 and 7 for comparison.

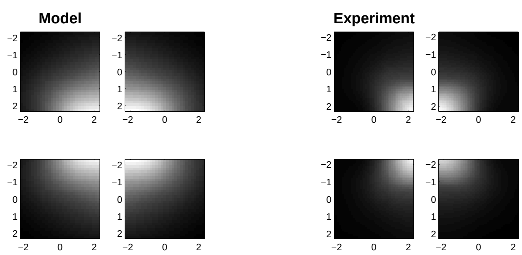

Figure 6: U21 beam, 7mm gap (distances in mm).

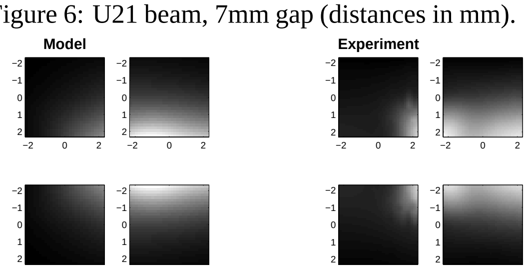

Figure 7: U21 beam, 25mm gap (distances in mm).

These results show that while sensible agreement is to be found between the model and reality, and that the model is a good indicator of what one can expect to find, there is still work to be done on refining the calculations. Generally speaking the models produce smooth photocurrent densities, whereas scan measurement shows sharper ones. The modelled bending magnet influence extends further into the centre of the undulator beam pipe than is found experimentally. This increased influence is what accounts for the greater modelled beam displacement seen in Figure 5.

These results suggest that in simulations the tip of the blade may need to be weighted more heavily to account for increased photoionization near the centre of the beam. Further work is ongoing in order to quantify how the blade thickness may influence the photoionization rates.

At present the effects of interference between undulator radiation and dipole radiation (and interference between dipoles) have been considered negligible as a first approximation. Incoherent beams of synchrotron light have been modelled. Improved models may need to evaluate the effects of possible interference fringes.

With regard to using the XBPMs as monitoring devices, it has been observed that the dipole causes a systematic error that influences the absolute position values produced by the XBPMs. However, modelling shows that the XBPMs can still produce reliable relative position for small changes to the ID gap. In addition, there is a very good correlation between movements in position and angle seen by the XBPMs and movements seen by the electron BPMs. When correctly calibrated the XBPMs will still measure the relative motion of the centre of mass of the beam accurately. Large changes in gap alter the ratio of undulator radiation to dipole radiation and are harder to correct.

CONCLUDING REMARKS

The model of the XBPMs using SRW/Matlab proves to be in a good quantitative agreement with XBPM experimental data, however, the results can be more accurate with a finer model. In particular further analysis is required in order to more accurately simulate blade photoionization rates. The scans provide useful information on the aperture seen by the photon beam, and to image the general beam shape in order to properly position the XBPM with respect to the beam. In addition, it allows study of the edge radiation effects on the monitor to be done, and eventually to provide corrections towards an absolute position.

The prospect of running the machine in top-up mode, i.e. with constant storage ring current, gives the possibility to correct for the edge radiation effects as it will become a constant error and it is straightforward to subtract from XBPM readings.

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