ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPM037

INVESTIGATIONS INTO OPERATING PULSE PICKING BY RESONANT EXCITATION (PPRE) IN THE VERTICAL PLANE

S. Wilkes[1]*, A. F. D. Morgan, M. Warren, G. Karras, I. Martin
Diamond Light Source, Oxfordshire, United Kingdom
[1]also at John Adam's Institute, University of Oxford, United Kingdom

Abstract

As preparation for the upcoming Diamond-II upgrade, provisions for timing-users (those who predominantly care about the temporal characteristics of the synchrotron radiation) are being investigated. Although 'Hybrid Mode' is currently employed at Diamond, such operation presents challenges for Diamond-II that merit investigating alternative approaches. Pulse Picking by Resonant Excitation (PPRE) is one such approach, which resonantly excites a targeted electron bunch. At Diamond this would be achieved using its Multi Bunch Feedback (MBF) system. Light sources currently operate PPRE in the horizontal plane, but users would prefer the vertical. In this paper we report on using the MBF to excite the electron beam in the vertical plane, showing the relationship between MBF gain and beam size. Furthermore, along with a representative beamline, I19, we present a rapid method to switch between standard collection and PPRE. Finally, our first results are presented.

INTRODUCTION

Timing mode studies are those that both resolve and utilise the temporal properties of the synchrotron X-ray pulses. Operating within this regime allows users to capture a range of physical phenomena, with methods ranging from synchronising time-of-flight mass-spectrometry experiments [1] to imaging transient effects [2]. Though these experiments only represent a small fraction of the experiments, facilitating a broad range of science is a key remit of a synchrotron facility. As part of Diamond's work into its future upgrade, Diamond-II [3], work is underway to understand the applicability of various schema for its timing mode users. Currently, Diamond can use a 'Hybrid Mode' fill pattern which consists of a highly charged bunch separated from the rest of a multi-bunch train. Unfortunately, for Diamond-II, operating Hybrid Mode reduces the effectiveness of the passive harmonic cavities that will be installed, which affects lifetime. One alternative is 'Pulse Picking by Resonant Excitation' (PPRE) [4]. Importantly, this has the benefit of being allowed to run alongside standard users.

PPRE does away with special fill patterns by instead exciting a single bunch; the light from this bunch is separated from the rest of the unperturbed bunch train in order to achieve a single-bunch-like effect (see Fig. 1). Though PPRE is already successfully implemented at BESSY [5], there will be new challenges at Diamond-II; namely the significantly smaller transverse electron beam size that must compete with inherent diffraction effects. Within this paper, we demonstrate the core principles of PPRE's operation at Diamond by characterising the photon-beam on a representative beamline (I19). Specifically, we investigate driving in the vertical plane, which better meets the needs of users. What is more, what we observe at Diamond will provide strong insight into what will be seen at Diamond-II due to the similar operating conditions.

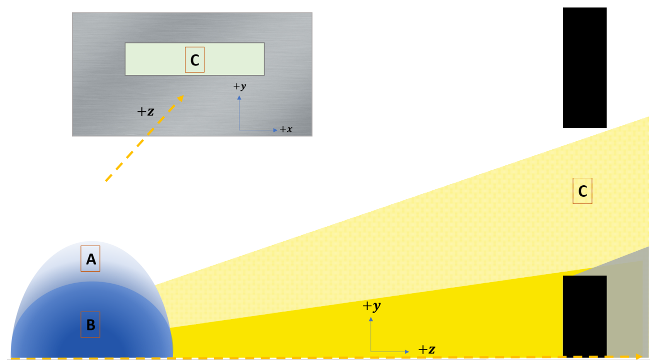

Figure 1: As each bunch emits synchrotron radiation, the various apertures on the optical beamline (C) must be positioned such that the light from the nominal bunches (B) is blocked, while ensuring that the light from the excited bunch (A) is able to pass through.

EXCITATION SETUP

A Multi Bunch Feedback (MBF) excitation oscillator for the vertical axis was tuned to lock onto the synchrotron sideband of the vertical tune. This reduces centroid motion; see [6] for more details. The strength of excitation determines the amount of beam-growth in the vertical plane [7].

Initially the x-ray pinhole cameras were used to measure this change in electron beam size. Latterly, cameras on I19 were used for the same purpose – indicative of a user's experience. While for the purposes of this initial experiment all bunches were excited, in the final application it is envisaged that the users can select the bunches they wish to enlarge. Thus, with the MBF, users can tailor the time-regime to optimise experimental conditions for their project.

MEASUREMENT WITH X-RAY PINHOLE CAMERA

Two X-ray pinhole cameras have been installed as part of Diamond's passive diagnostic tool set [8]. Diamond's emittance and energy spread calculations are performed with these devices as part of its standard operation, however for

* juan.martinezwilkes@physics.ox.ac.uk

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPM037

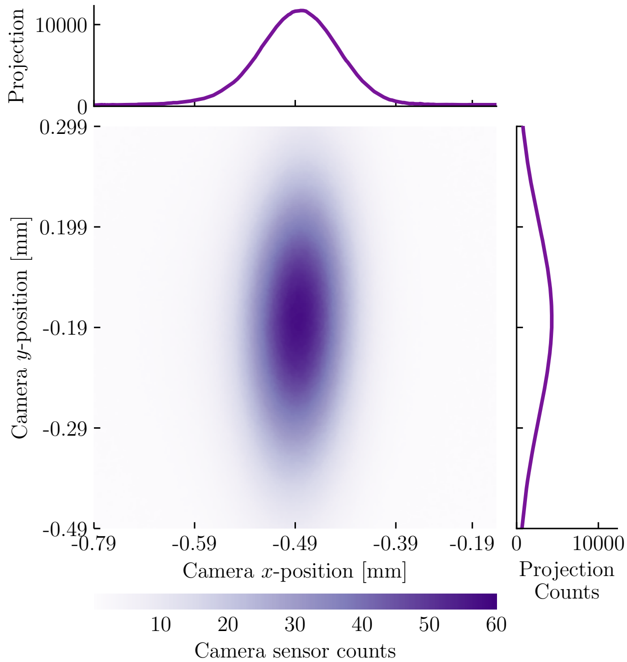

Figure 2: A snapshot from the X-ray pinhole camera feed of the electron beam being excited with the MBF at -7 dB.

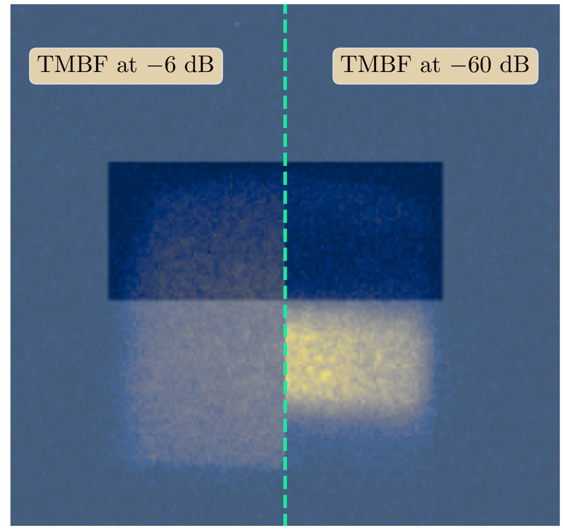

Figure 3: The camera images taken within I19, which are used to image the photon beam, are compared between the MBF at maximum strength (LHS) and the MBF effectively off (RHS). The window indicates what would be seen by a user in the experimental area. Camera settings remain otherwise unchanged. See colour version for best clarity.

this experiment we were additionally able to pull its image data directly, e.g. see Fig. 2. The camera's attenuators were wound out to increase flux capture at large emittances, and the auto-exposure left on for the emittance measurements. This approach is good as a first pass to evaluate the conditions for PPRE, as it requires minimal setting up. Furthermore, it is quick to take take multiple images (to quantify variance) as the camera refresh rate is ~ 5 Hz.

Once the data was collected, we used sciPy's `medfilt2d` function (a 2D median filter) [9] to remove stuck / dead pixels. The advantage of this filter is that the smoothing effect is not too strong, but successfully eliminates any of the aforementioned (static) outliers.

MEASUREMENT USING I19 BEAMLINE

I19 is an advanced optical beamline that specialises in 'Small Molecule Single Crystal (X-Ray) Diffraction', operating photon energies between 5 keV and 25 keV. For our measuring purposes, I19 serves as a sophisticated X-ray camera. Its results are far more illustrative of what future users at Diamond-II would experience. For instance, their Double Crystal Monochromator (DCM) is designed for the demands of beamline users, resulting in a narrower band of frequencies passing through, simplifying our analysis and resulting conclusions. For our experiment, I19 was set up to image 25 keV photons. To image the photon beam, a thin sintered diamond, which fluoresces under X-ray exposure, is placed after the DCM. A camera then records this fluorescence.

For the experiment, a method to switch between standard collection and timing mode, within a matter of seconds, was considered. By altering the DCM's vertical offset, which for our experiment was from 19.00 mm to 20.33 mm, the benefits were two fold. One, it quickly allowed us to investigate the requirements of light separation. Secondly, it increased the distance between the photon beam centre and a region of clipping. As the electron bunch size was increased, the expanded photon beam profile would fill the sensor area corresponding to user imaging (see Fig. 3). After setting the MBF Excitation Gain, we saved the image output for later analysis, repeating this step for various gains.

There were fewer dead pixels on the camera used at I19 than with the X-ray pinhole; it was simple enough to manually set the errant pixels to 0, and do without the median filtering. At this point, to count the signal the region designated for the user imaging is summed.

To calculate the photon beam size, the image data was projected onto the y-axis to get a marginal distribution. From this, one can compute the FWHM of the photon distribution. Due to the limited aperture profile for the photon beam to pass through, atop of now being positioned off axis, there was some concern that the lower side of the photon beam was being clipped. To compensate for this effect, $\frac{1}{2}$FWHM was computed using only the upper-half of the data distribution away from the clipping edge. This estimate was then multiplied by 2 to get a new estimated FWHM.

DISCUSSION OF RESULTS

A qualitative assessment shows that at sufficiently large MBF gain, the transverse profile (size) of the electron beam switches from $\sigma_x > \sigma_y$ to $\sigma_y > \sigma_x$.

Looking at quantitative features, the MBF was able to increase the vertical electron beam size by up to a factor

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPM037

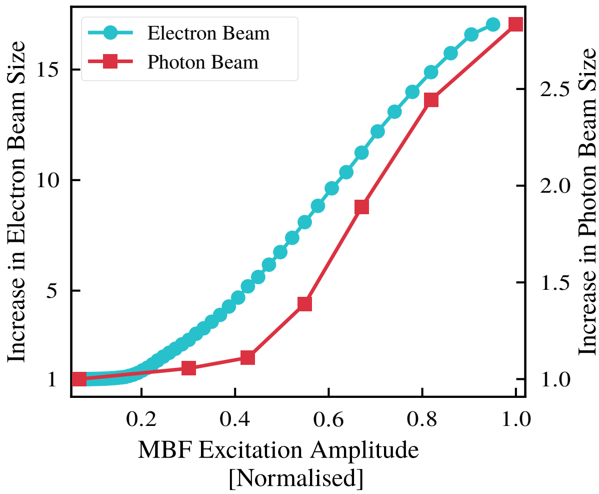

Figure 4: The relative (experimentally obtained) increase in both the size of the electron and photon beams is plotted against a normalised MBF excitation amplitude (converted from gain, and normalised to value at -6 dB). Note, the fine-grained scan of electron emittance data was collected at a later date, meaning the correspondence between MBF excitation gain and amplitude may not be exactly the same in both runs.

of ~17 (Fig. 4). This corresponded to an increase in the vertical photon beam size of ~ 2.5× (Fig. 4). As the MBF gain is increased, thus excitation amplitude, the electron beam emittance increases. In turn, so does the size of the photon beam as measured at I19. Nonetheless, the electron beam initially is dominated by stochastic effects [6] before growing approximately linearly; the photon beam growth is then seen soon afterwards. Future experiments on I19 should ensure repeat multiple readings in order to quantify variability.

OUTLOOK TO DIAMOND-II

The results presented here are indicative of what users would experience by using PPRE at Diamond-II. This is largely because the vertical emittance will remain the same for Diamond-II as for Diamond. There are a few changes to consider. The horizontal emittance will be $\lesssim$ 20× smaller. Though this would further increase the elongation ratio, this reduction in emittance would naturally increase the measured intensity found by Diamond-II's users. Furthermore, given that a beamline like I19 operates at moderate to high photon energies, the flux observed would also increase at Diamond-II due to its higher operational electron beam energy (3.5 GeV vs 3.0 GeV).

On the other hand, Diamond-II will employ a passive harmonic cavity (PHC) that substantially alters the longitudinal dynamics; in turn, through chromatic coupling, affecting the transverse. The vertical excitation resonance profile (e.g. synchrotron sidebands) will be smeared out in Diamond-II, reducing the maximum effect from the MBF, thus reducing the maximum obtainable photon size. These effects are currently being quantified.

CONCLUSION

We have demonstrated that Diamond's Multi Bunch Feedback (MBF) was able to perform significant vertical driving of its electron beam (Fig. 4), as part of work towards providing 'Pulse Picking by Resonant Excitation' (PPRE) for timing mode users. Other light sources currently operate PPRE in the horizontal plane, whereas opting for the vertical plane would be preferred by users. The relationship between electron beam emittance and the MBF excitation gain was also plotted. Similarly, we have shown the growth of the photon beam size, within a representative optical beamline, I19 as a function of the MBF kick strength (Fig. 4).

The goal of future work is to confirm the practicality for users to adopt PPRE. This paper has shown the foundations to investigate PPRE in the vertical plane by our use of beam imaging and characterisation, though further adjustments and tuning need to be explored. This paper has also suggested a possible alternative to electron beam steering as a way to physically separate light from PPRE bunches from the rest of the electron beam train. This was achieved by physically displacing the double crystal monochromator in I19. Hence, this simple method was able to move the photon beam off the optical axis, allowing the excited beam to expand back onto the optical axis. These reported measurements provide strong insight into what experimental conditions users on Diamond-II may be able to expect whilst using PPRE.

ACKNOWLEDGEMENTS

Project funded by a joint STFC-Diamond studentship (ST/W507532/1), supervised by Prof. Philip Burrows and Dr Ian Martin.

REFERENCES

[1] A. Born, F. O. L. Johansson, T. Leitner, D. Kühn, *et al.*, "Separation of surface oxide from bulk Ni by selective Ni 3p photoelectron spectroscopy for chemical analysis in coincidence with Ni M-edge Auger electrons," *Scientific Reports*, vol. 11, no. 1, p. 16596, Aug. 2021. doi:10.1038/s41598-021-96108-x

[2] M. Fondell, S. Eckert, R. M. Jay, C. Weniger, *et al.*, "Time-resolved soft X-ray absorption spectroscopy in transmission mode on liquids at MHz repetition rates," *Structural Dynamics*, vol. 4, no. 5, p. 054902, Sep. 2017. doi:10.1063/1.4993755

[3] R. Walker *et al.*, "Diamond-II Technical Design Report," Tech. Rep., 2023. https://www.diamond.ac.uk/Home/News/LatestNews/2022/14-10-22.html

[4] K. Holldack, R. Ovsyannikov, P. Kuske, R. Müller *et al.*, "Single bunch X-ray pulses on demand from a multi-bunch synchrotron radiation source," *Nature Communications*, vol. 5, no. 1, p. 4010, May 2014. doi:10.1038/ncomms5010

[5] R. Müller, T. Birke, F. Falkenstern, H. Glass, *et al.*, "BESSY II Supports an Extensive Suite of Timing Experiments", in *Proc. IPAC'16*, Busan, Korea, May 2016, pp. 2840–2843. doi:10.18429/JACoW-IPAC2016-WEPOW011

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPM037

[6] S. Wilkes, "Lifetime without Compromise", presented at the IPAC'23, Venice, Italy, May 2023, paper MOPM036, this conference.

[7] S. Preston, L. Bobb, A. Morgan, and T. Olsson, "Measurements for Emittance Feedback based on Resonant Excitation at Diamond Light Source", in *Proc. IBIC'22*, Kraków, Poland, Sep. 2022, pp. 492–495. doi:10.18429/JACoW-IBIC2022-WEP37

[8] L. Bobb and G. Rehm, "Spatial Resolution of an X-ray Pinhole Camera using a Multi-layer Monochromator", in *Proc. IBIC'19*, Malmö, Sweden, Sep. 2019, pp. 417–419. doi:10.18429/JACoW-IBIC2019-TUPP038

[9] "sciPy 2D median filter," https://docs.scipy.org/doc/scipy/reference/generated/scipy.signal.medfilt2d.html#scipy.signal.medfilt2d, Accessed: 02/05/2023.