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EMITTANCE FEEDBACK FOR THE DIAMOND-II STORAGE RING USING RESONANT EXCITATION

S. Preston*, T. Olsson, B. Singh, Diamond Light Source, Oxfordshire, UK

Abstract

In the Diamond Light Source storage ring, the vertical emittance is kept at 8 pm rad during operation to maintain the source brightness for the users. This is achieved by a feedback which modifies the skew quadrupole strengths, but has disadvantages such as the introduction of betatron coupling and vertical dispersion. For the proposed Diamond-II upgrade, the storage ring will have a much smaller horizontal emittance, meaning a significantly larger coupling would be required to reach the target vertical emittance, negatively affecting the off-axis injection process. To solve this problem, a feedback using the transverse multibunch feedback striplines to drive the beam at a synchrotron sideband is planned. By driving the beam resonantly in this way, the emittance can be increased without modification of the optics. This paper describes simulations of the effects of linear and non-linear optics on the excitation as well as the impact of the machine impedance for the Diamond-II storage ring.

INTRODUCTION

In synchrotron light storage rings, the emittance of the beam must be controlled during operations to stabilise the source brightness and lifetime for users as conditions vary due to long-term drifts and insertion device (ID) gap movement. At the existing Diamond storage ring, the vertical emittance is kept at 8 pm rad by a feedback which modifies the skew quadrupole strengths [1], but this introduces betatron coupling and vertical dispersion. An upgrade of the ring is planned [2] to significantly reduce the horizontal emittance, meaning the new Diamond-II storage ring will require a larger coupling to reach the same vertical emittance, affecting the off-axis injection. Studies at BESSY II and MAX IV [3–6] have shown that the emittance can be blown up by driving the beam at a synchrotron sideband. The purpose of those studies was to increase the emittance of a single bunch to provide light for timing users while operating with a multi-bunch fill pattern [7], but at Diamond the same method is planned to be used for an emittance feedback acting on all bunches without affecting the optics. The emittance will be measured using the existing pinhole cameras and then the feedback will adjust the gain of an excitation from the multi-bunch feedback striplines, to keep the emittance at the target value. The vertical emittance will first be corrected to a few pm rad using LOCO [8] and then increased to 8 pm rad with the emittance feedback. This paper presents simulations of the effect of linear and non-linear optics as well as impedance on the optimal excitation frequency for the Diamond-II storage ring.

* shaun.preston@diamond.ac.uk

SIMULATION SETUP

Simulations were performed in Elegant [9, 10] including broadband impedance given by the sum of the resistive-wall and geometric contributions [11]. A bunch of 1,000 particles was tracked to equilibrium using a one-turn map including radiation damping, quantum excitation and non-linear optics terms (second and third order chromaticity, and amplitude-dependent tune shifts). The bunch was excited vertically using a zero-length kicker with a sinusoidal kick angle given by

$$\theta = A\cos(2\pi f t) \tag{1}$$

where A is the maximum kick angle, f the excitation frequency and t the arrival time at the kicker.

SIDEBAND DISTORTION

Figure 1 shows the beam oscillation and size as a function of excitation frequency. The symmetry of the synchrotron sidebands is broken by the impedance and non-linear terms. The impedance widens and shifts them closer to the tune while the non-linear terms narrow the lower sidebands.

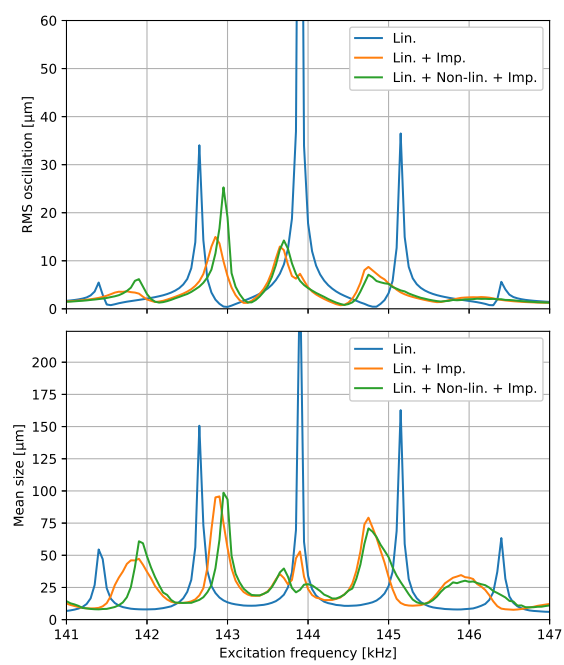

Figure 1: Beam oscillation and size as a function of excitation frequency due to linear chromaticity, non-linear terms and impedance at nominal bunch current 0.32 mA and vertical chromaticity 2.33 for a kick angle of 50 nrad. Black lines mark the nominal positions of the vertical betatron tune (solid) and synchrotron sidebands (dashed).

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IMPEDANCE EFFECTS

Transverse

Figure 2 shows how the beam oscillation and size vary with current due to transverse impedance. The effect comes from the vertical impedance as the horizontal contribution has no impact. At the upper synchrotron sidebands, the beam oscillation and size decrease with current while the opposite is true at the lower sidebands. It is also seen that the tune peak bifurcates and becomes weaker with current, for both the beam oscillation and size. Typically, the first synchrotron sidebands produce the greatest increase in size to oscillation compared to the second sidebands, but with increasing current, the second lower sideband also produces a large increase in beam size and maintains a comparatively small oscillation, making it a potential candidate for excitation.

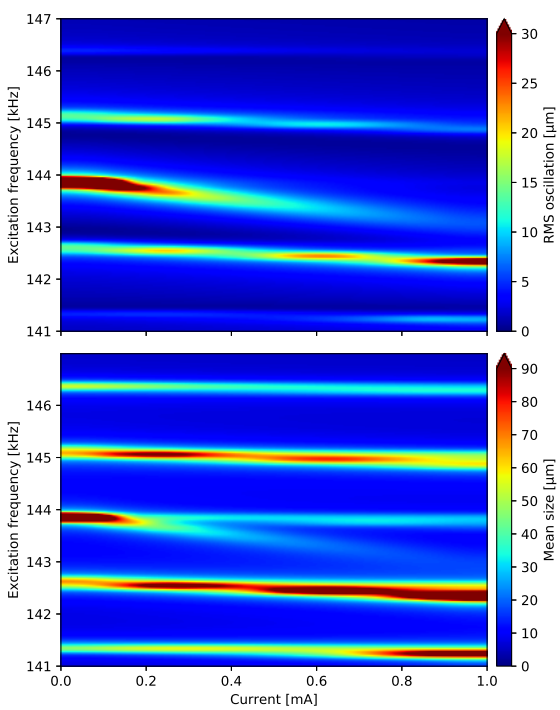

Figure 2: Beam oscillation (top) and size (bottom) as a function of current due to transverse impedance at vertical chromaticity 2.33 for a kick angle of 50 nrad. Non-linear terms and longitudinal impedance are not included.

Longitudinal

Figure 3 shows how the beam oscillation and size vary with current due to longitudinal impedance. The upper and lower synchrotron sidebands demonstrate similar behaviour and shift closer to the vertical betatron tune, while becoming broader as the bunch current is increased.

Transverse + Longitudinal

Figure 4 shows the ratio of the beam size to the oscillation including both transverse and longitudinal impedance to highlight how the optimal excitation frequency changes with

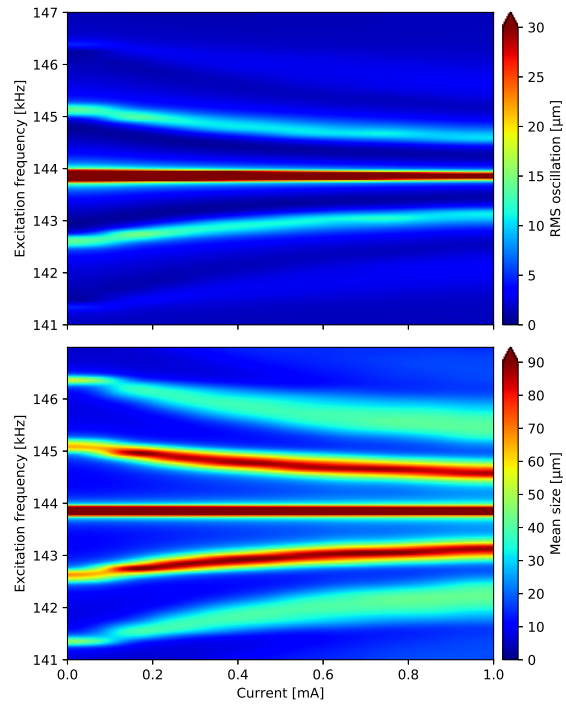

Figure 3: Beam oscillation (top) and size (bottom) as a function of current due to longitudinal impedance at vertical chromaticity 2.33 for a kick angle of 50 nrad. Non-linear terms and transverse impedance are not included.

current. For low current, the first lower synchrotron sideband produces the largest ratio, but at nominal bunch current (0.32 mA) the first upper sideband becomes better. The figure also shows that the sidebands are sensitive to changes in linear chromaticity. The first upper synchrotron sideband is the best candidate at chromaticity 1, becoming broader at high currents, but with increasing chromaticity and current there is little difference in exciting between upper and lower sidebands. In general, higher chromaticity produces larger ratios.

EMITTANCE GROWTH

As the emittance of the beam changes due to ID gap changes and other external factors, the feedback will have to adjust the kick angle given by the stripline kicker to maintain the target emittance. It is therefore of interest to understand the relationship between kick angle and emittance increase. If the emittance increase at the chosen excitation frequency is small, it will have to be compensated for with a larger kick, increasing the oscillation of the beam. The maximum kick angle used in the simulations was far below the technical limitations of the multi-bunch feedback system which implies that compromising between the ratio and size is irrelevant for Diamond-II, since a large blow up of the emittance can be achieved with a very small kick angle. In Fig. 5, it can be seen that the emittance grows quadratically for small kick angles whereas the beam size grows linearly. It is also shown

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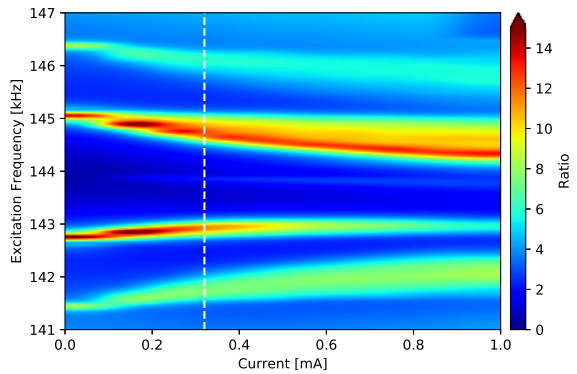
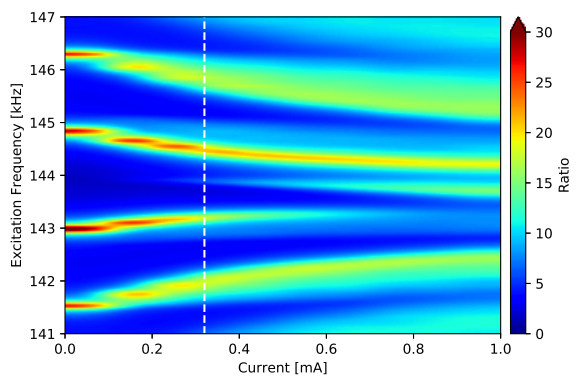
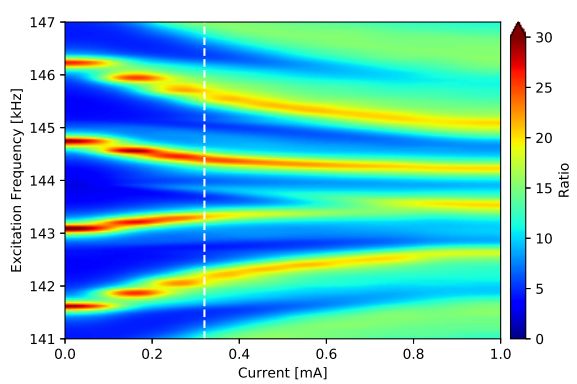


(a) Vertical chromaticity 1



(b) Vertical chromaticity 2.33



(c) Vertical chromaticity 3

Figure 4: Ratio of the mean beam size to RMS oscillation as a function of current due to transverse and longitudinal impedance at different vertical chromaticity for a kick angle of 50 nrad. A dashed white line shows the nominal bunch current (0.32 mA). Non-linear terms are not included.

that the impedance has a significant effect on the growth rate. As the kick angle is increased to hundreds of nrad, amplitude-dependent tune shifts start to dominate, which causes the growth of the emittance to plateau.

CONCLUSIONS AND FUTURE WORK

The studies show that the upper first synchrotron sideband is the optimal excitation frequency because it gives the best

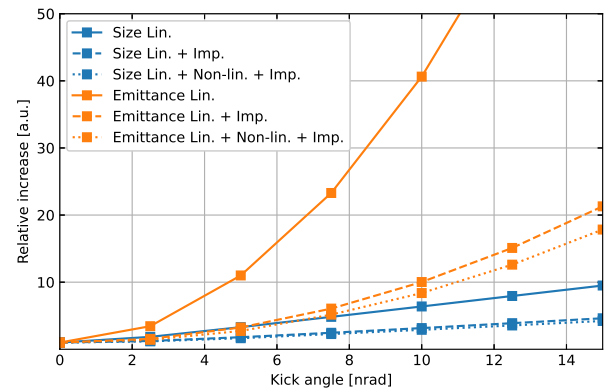


Figure 5: Relative increase in beam size (σ/σ_0) and emittance (ϵ/ϵ_0) at the first upper synchrotron sideband as a function of kick angle due to linear chromaticity, non-linear terms and impedance at the nominal bunch current 0.32 mA and vertical chromaticity 2.33.

ratio between beam size and oscillation. The studies also show that both the non-linear optics terms and impedance cause a broadening of the sidebands, which suggests that the beam can be excited at a large range of frequencies to achieve emittance increase. The impedance however has a much larger effect on the optimal frequency than the non-linear terms for the nominal current and target emittance of the Diamond-II storage ring. Studies are ongoing of the effect of a harmonic cavity since the ring is planned to operate with a passive superconducting third order harmonic cavity. Benchmarking between simulations and measurements is also planned at the existing Diamond storage ring to understand how well the simulations predict the real behaviour with current. Of special interest is how the magnitude of the kick angle in simulation compares to the required kick angle in the machine to achieve the same emittance increase. It is also of interest to study if the multi-bunch feedback can help to mitigate the beam oscillation driven by the excitation and thus improve the ratio between the beam size and oscillation.

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REFERENCES

[1] I. P. S. Martin, M. G. Abbott, M. Apollonio, D. Hickin, and R. Bartolini, "Operating the Diamond Storage Ring with Reduced Vertical Emittance", in *Proc. IPAC'13*, Shanghai, China, May 2013, paper MOPEA071, pp. 249–251.

[2] "Diamond-II Technical Design Report", Diamond Light Source, to be published, `https://www.diamond.ac.uk/Home/About/Vision/Diamond-II.html`

[3] J. G. Hwang, M. Koopmans, M. Ries, A. Schälicke, and R. Müller, "Analytical and numerical analysis of longitudinally

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coupled transverse dynamics of pulse picking by resonant excitation in storage rings serving timing and high-flux users simultaneously", *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 940, pp. 387-392, 2019, doi:10.1016/j.nima.2019.06.053

[4] R. Mueller *et al.*, "Pseudo Single Bunch Qualities Added to Short Pulse Operation of BESSY II", in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 2574–2577. doi:10. 18429/JACoW-IPAC2017-WEPAB007

[5] T. Olsson, Å. Andersson, "First Measurements of Pulse Picking by Resonant Excitation (PPRE) at the MAX IV 3 GeV Storage Ring", in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 2750–2752. doi:10.18429/JACoW-IPAC2017-WEPAB073

[6] T. Olsson, Å. Andersson, and D. K. Olsson, "Pulse-Picking by Resonant Excitation (PPRE) for Timing Users at the MAX IV 3 GeV Storage Ring", in *Proc. IPAC'18*, Vancouver, Canada, Apr.-May 2018, pp. 4300–4303. doi:10.18429/JACoW-IPAC2018-THPMK004

[7] K. Holldack *et al.*, "Single bunch x-ray pulses on demand from a multi-bunch synchrotron radiation source", *Nat. Commun.*, vol. 5, no. 4010, May 2014, doi:10.1038/ncomms5010

[8] J. Safranek, "Experimental determination of storage ring optics using orbit response measurements", *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 388, pp. 27-36, 1997, doi:10.1016/S0168-9002(97)00309-4

[9] M. Borland, "Elegant: A Flexible SDDS-compliant Code for Accelerator Simulation", Argonne National Lab., Illinois, USA, 2000.

[10] Y. Wang, M. Borland, "Pelegant: A Parallel Accelerator Sim-ulation Code for Electron Generation and Tracking", *AIP Conf. Proc.,* vol. 877, 241, 2006. doi:10.1063/1.2409141

[11] R. T. Fielder, H. C. Chao, and S. W. Wang, "Single Bunch In-stability Studies with a New Impedance Lattice for Diamond-II", in *Proc. IPAC'22*, Bangkok, Thailand, Jun. 2022, paper WEPOMS011.