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MEASUREMENTS FOR EMITTANCE FEEDBACK BASED ON RESONANT EXCITATION AT DIAMOND LIGHT SOURCE

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Abstract

In the Diamond storage ring, the vertical emittance is kept at 8 pm rad by an emittance feedback which modifies the strengths of skew quadrupoles. A new feedback using a stripline kicker to control the vertical emittance by exciting the beam resonantly at a synchrotron sideband is planned to avoid modification of the optics. This is crucial for the anticipated Diamond-II upgrade of the storage ring, which will have a much smaller equilibrium emittance than the existing machine. A larger coupling is therefore needed to keep the vertical emittance at the same level, potentially reducing the off-axis injection efficiency and lifetime. Measurements of the beam oscillation and emittance have been performed at the existing storage ring to characterise the effects of chromaticity and impedance on the optimal excitation frequency, where the emittance is increased significantly while the beam oscillation is kept low. The implications for simulating the emittance feedback for the Diamond-II storage ring are also discussed.

INTRODUCTION

The vertical emittance of the Diamond Light Source storage ring is kept constant during user operation by a feedback system to maintain the source brightness, spot size and coherence as conditions in the machine change [1]. Before each machine run, the optics are corrected using LOCO [2], giving a vertical emittance on the order of a few pm rad. The emittance is then measured using two pinhole cameras and increased to 8 pm rad by changing the strengths of the skew quadrupoles in the ring [1]. This results in changes of the optics such as betatron coupling and vertical dispersion. Although not a concern for the existing ring, it could negatively affect the off-axis injection efficiency and lifetime for the planned Diamond-II storage ring, which will reduce the equilibrium emittance from 2.7 nm rad to 160 pm rad with open insertion devices and 120 pm rad with closed [3]. The required coupling to reach the same level of vertical emittance will then be considerably higher.

A new emittance feedback that does not affect the optics is therefore under development. Inspiration comes from the pulse picking by resonant excitation (PPRE) method operated at BESSY-II [4, 5], where the emittance of a single bunch is increased by driving the beam at a synchrotron sideband. The purpose is to extract single bunch light for timing users while operating with a multi-bunch fill pattern. At Diamond, the plan is to drive all the bunches and use a feedback system to adjust the excitation amplitude to keep the emittance constant.

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Measurements at different excitation frequencies have been done at the existing Diamond storage ring. The optimal frequency and implications for predicting the behaviour of the Diamond-II storage ring are discussed. The new emittance feedback is also presented along with future plans.

THE DIAMOND MULTI-BUNCH FEEDBACK SYSTEM

The transverse multi-bunch feedback system (TMBF) for the Diamond storage ring is developed in-house. It uses a beam position monitor (BPM) to detect turn-by-turn bunch-by-bunch data and stripline kickers to apply excitation to the beam. More details about the hardware can be found in [6–8]. The system can apply multiple concurrent excitations to user defined groups of bunches, down to the level of a single bunch. In user operation, it is used both to damp coupled-bunch instabilities and for low gain frequency sweeps to measure the betatron and synchrotron tunes for tune feedback. During machine development, it is also used to drive the beam for instability studies.

FEEDBACK IMPLEMENTATION

The emittance feedback is implemented using the TMBF system for excitation and the existing pinhole cameras for measurement. An additional excitor is used to drive the beam at one of the synchrotron sidebands. In practice, this is realised by using a numerically controlled oscillator (NCO), whose amplitude and frequency can be adjusted as needed.

In order to implement the feedback, an additional control loop was added, which adjusts the amplitude of the NCO in order to maintain a target value of emittance. As in the existing emittance feedback system, the change in beam size is monitored by two pinhole cameras and the emittance calculated using this data.

To improve the effectiveness of the technique, tune tracking is also implemented. The purpose of tracking is to allow the excitation to follow the jitter in tune, which causes the excitation to stay on the peak of the desired sideband. This is achieved by using a phase-locked loop which monitors a single tracking bunch.

Interference can be reduced by turning off the TMBF system tune sweep for the tracking bunch and a few bunches either side and not applying an emittance excitation to them. These bunches only need a fraction of the charge of the others for sufficient lifetime without an emittance increase.

The feedback has run successfully in dedicated development time and is being integrated into the existing control system, which will allow switching between the existing skew quadrupole and sideband excitation methods for user operation.

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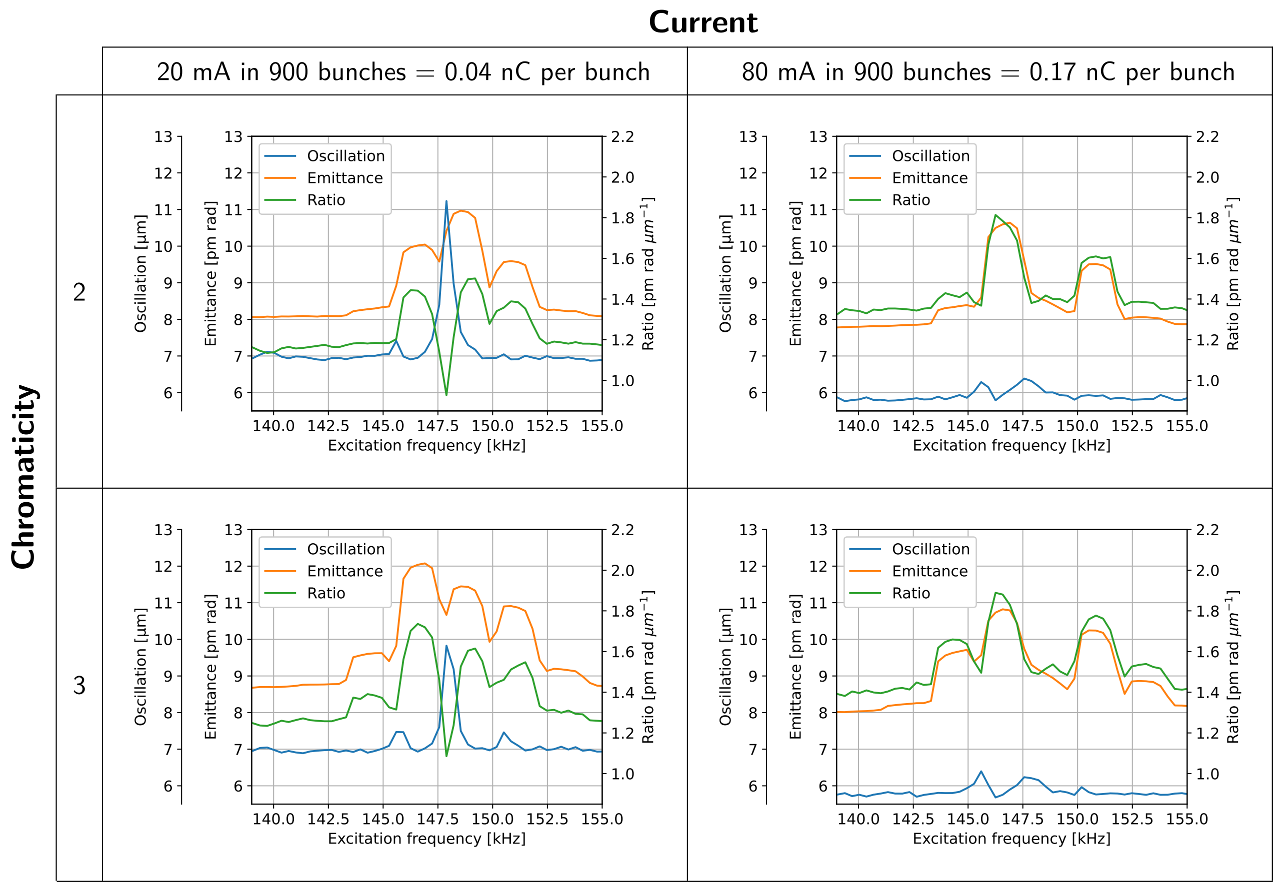

Figure 1: Measurements of beam RMS oscillation, vertical emittance and ratio of emittance to oscillation as a function of excitation frequency for different chromaticities (rows) and currents (columns). The ring was operated with a train of 900 bunches during the measurements. The gain of the excitation was set to −42 dB.

MEASUREMENTS OF EMITTANCE EXCITATION

The measurements were done using the TMBF system to excite the beam vertically over a frequency range including both the betatron tune and the first synchrotron sidebands. The oscillation of the beam was measured by extracting turn-by-turn data from the BPMs and calculating the RMS of the motion, whereas the emittance was extracted from the beam size measured by two pinhole cameras [9] at different positions in the ring. To get sufficient signal for the pinholes with low single bunch current, it was necessary to operate with a multi-bunch fill pattern in the machine. The measurements were therefore done using the normal fill pattern of 900 bunches. All of the insertion devices were open and the two superconducting wigglers turned off to give a lattice as close to bare as possible. Since the pinholes average over time, the measured beam size is a sum of the beam oscillation and emittance increase which has to be considered when comparing to simulations. Figure 1 shows the beam oscillation and vertical emittance for two different chromaticites and currents. Increasing the chromaticity makes additional sideband peaks appear and a strong current-dependent behaviour is observed, meaning the impedance is important. All of the measurements were taken using the same gain, but some at a higher current. This resulted in both smaller oscillation and emittance, so more gain is required at higher currents to get the same effect on the beam.

The ratio of the emittance to oscillation changes with current and chromaticity, which suggests that the optimal excitation frequency depends on the machine conditions. An empirical approach might be required where a good frequency is found during the setup of the machine by performing a frequency sweep. However, the measurements show that a good working point could be around the first lower synchrotron sideband, since the ratio is largest at this point for most of the measurements.

A complete impedance model does not currently exist for the Diamond storage ring, but previous measurements have been performed to fit a model consisting of broadband resonators, resistive-wall and an inductive component [10]. Using this model, simulations were run in `Elegant` [11,12] to see if the behaviour observed in the measurements could be reproduced. The simulations were done using a single bunch and only broadband impedance as had previously been done for the Diamond-II storage ring, presented in more detail in [13]. The simulations showed similar behaviour with chromaticity as the measurements and the simulations

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for Diamond-II, where additional synchrotron sidebands became visible with increasing chromaticity. It however proved difficult to achieve good agreement with the measurements at different currents. The addition of impedance broadened the peaks and made the lower and upper sidebands asymmetric as seen in the measurements, but the effect of the impedance was too weak. The current hypothesis is that the discrepancy comes from not including the effect of the long range wakefields in the model. The measurements were done around vertical coupled-bunch mode 0 out of a total 936 modes, but the TMBF system can also excite the beam around the other coupled-bunch modes given by the frequencies

$$f = \mu f_0 + \Delta f_\beta, \tag{1}$$

where μ is the coupled-bunch mode number (0-935), f_0 the revolution frequency and Δf_β the fractional part of the betatron tune converted to frequency [14].

During user operation, the TMBF system does a continuous frequency sweep with a very small gain to measure the tune. This is normally done around mode 80, but can be conducted around any mode. Figure 2 shows a comparison of the tune sweep around mode 0 and 80 for a case with a total current of 270 mA in the machine. The response of the beam changes with the coupled-bunch mode, which indicates that long range wakefields have a significant impact. This conclusion is also supported by a previous measurement of the coupled-bunch modes [15], where a tune sweep was performed around each mode and the mode damping times calculated from the Q factor when fitting a resonator to the tune peak. These fitted damping times showed good agreement with damping time extracted from drive-damp measurements. To predict the response of the beam from an excitation when operating with a multi-bunch fill pattern, it might therefore be necessary to include all the bunches and both short and long range wakefields in the simulation.

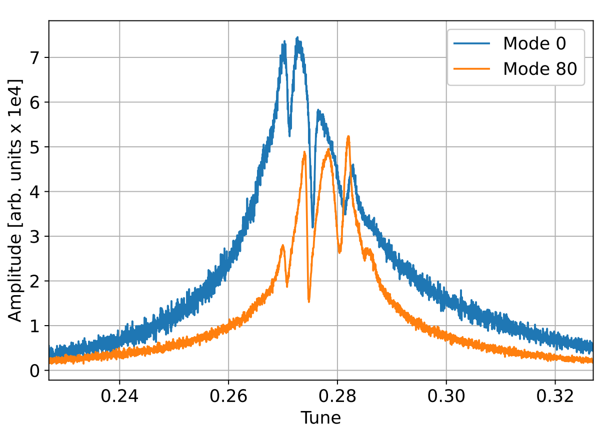

Figure 2: Comparison of vertical tune sweep around coupled-bunch mode 0 and 80 at 270 mA current.

DISCUSSION

A similar method to control the emittance is white noise excitation, which for example is used at ESRF [16]. In this method, the beam is excited at a broad range of frequencies instead of at a single frequency. The main advantage is that it is relatively simple to implement and that the method is insensitive to tune variations, which is useful for a machine without tune feedback. The disadvantage however is less separation between the emittance blow-up and betatron oscillations. Both tune and multi-bunch feedback is already implemented in the Diamond storage ring for other purposes, making emittance excitation using a single frequency easier to implement than white noise excitation. Using the multi-bunch feedback system for the excitation also has the advantage that the emittance of individual bunches can be manipulated, which might be of interest when operating with fill patterns, where a single bunch has been filled with higher charge for timing users. A larger excitation gain compared to the other bunches can then be given to the high-charge bunch to improve its lifetime while keeping the vertical emittance of the rest of the bunches at 8 pm rad. The new feedback also has the potential to control the horizontal emittance, which could be important for the Diamond-II storage ring, where the impact on the equilibrium emittance from the insertion devices is significant.

FUTURE WORK

The measurements highlighted some interesting areas that need to be studied further. Most important is the effect of coupled-bunch modes, which will require including both short and long range wakefields in the simulations. Also, to better understand the effect of the short range wakefields, additional measurements closer to operation with a single bunch in the ring could be done either by operating with a sparser fill pattern or by switching from measuring emittance to lifetime in case the signal is too weak for the pinholes.

Another interesting topic is the effect of the multi-bunch feedback on the beam oscillation. Since the feedback damps the dipole oscillations of the beam, it might counteract the oscillations driven by the excitation, and thus improve the ratio between the emittance blow-up and the beam oscillation.

For the Diamond-II storage ring, a detailed impedance model exists and simulations of emittance excitation for the case with a single bunch and short range wakefields have already been completed [13]. The measurements presented in this paper however indicate that the simulations for the new machine should be expanded to include the whole fill pattern and both short and long range wakefields to more accurately predict the behaviour and study how the optimal excitation frequency depends on the coupled-bunch modes.

The new storage ring will also include a harmonic cavity to increase the lifetime, reduce intra-beam scattering and mitigate instabilities by lengthening the electron bunches. This will drastically change the longitudinal dynamics of the beam, so the effect of the harmonic cavity on the emittance excitation must therefore be studied in more detail.

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