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CORRECTION OF 10 Hz ORBIT DISTORTION FROM DIAMOND'S I10 FAST SWITCHING CHICANE

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Abstract

The I10 beamline at Diamond Light Source is configured to study circular dichroism. To increase signal to noise ratio between the two beam polarisations and increase temporal resolution the beamline is fed by two separate IDs that are typically configured with opposite handed polarisations. A chicane of steering magnets with programmable power supplies is used to provide 10 Hz switching between the two photon beams by producing a dynamic closed bump that alternates the on-axis trajectory of the electron beam between the two IDs. In order to maintain the closed bump and make the switching transparent to the rest of the photon beamlines the phase and amplitude of the sine functions applied to the chicane magnets must be exactly correct. In this paper the linear scheme that was used to correct the residual 10 Hz orbit distortion is presented. Future work that uses the fully programmable nature of the magnet power supply controllers to correct high order distortions is also discussed.

INTRODUCTION

Diamond Light Source is a third generation synchrotron light source, with a 3 GeV storage ring, a 100 MeV linac and 3 GeV booster, allowing operation in top up mode [1]. Since commissioning Diamond have increased the number of photon beamlines and there are currently 33 which are either in operation or construction.

Adding to already established beamlines has allowed Diamond to explore more novel techniques when designing newer beamlines. One such technique in use for Diamond's I10 beamline is fast polarisation switching; chicane magnets are configured with an AC waveform to synchronously move the electron beam on or off axis between one of the two insertion devices (IDs) set to different polarisations, allowing rapid 10 Hz switching between the polarization of the on-axis beam [2]. This must be achieved without creating motion in the global electron beam which will be visible to other photon beamlines.

CONFIGURATION OF DIAMOND'S I10 BEAMLINE

Diamond's I10 beamline provides a platform for advanced dichroism experiments [3]. The two APPLE II undulators are capable of providing soft x-ray beams between 0.4 keV and 2 keV in arbitrary circular and linear polarisations [4, 5]. To determine the dichroism it is often necessary to resolve very small differences between the scans at different polarisations. By decreasing the time delay between the two spectra being obtained any time-based noise, such as thermal drift, can be minimized, and larger quantities of data can be collected and then averaged making better use of beamtime.

I10 CHICANE ARRANGEMENT

Third generation light sources have dedicated straight sections of storage ring designed for the placement of IDs; these are situated between the arcs of the machine which contain the bending and focusing magnets. In I10's straight there are two IDs and five dipole magnets, with a pair of fast dipoles situated either side of the IDs and one DC dipole between them as shown in Fig. 1. This provides the actuation necessary to change the path of the electron beam such that the angle can be controlled through each ID while ensuring that the exit trajectory of the electrons maintains a constant angle and position. The chicane magnets are each powered with an offset sine wave that switches the beam between its two states at 10 Hz. Preventing any global movement in the electron beam is particularly important for the other beamlines where the requirements for beam stability are high, with beam motion < 10 % of beam size; this ensures a stable x-ray beam for Diamond's users [6]. Any error in the steering through the chicane will allow the 10 Hz component to leak out of the chicane and into the global electron beam motion.

Magnet Details

The chicane magnets are horizontally deflecting magnets arranged symmetrically about the IDs. Despite the symmetric arrangement slight variations in manufacturing necessitate slightly different set-points for the magnitude of the sine waveforms of the complementary magnets. Each complementary pair of magnets has its waveform separated in phase by 180°. The field on the magnets is brought through a synchronised sine wave sweep so that the two extreme states shown in Fig. 1 are cycled between at 10 Hz. Carefully controlling the magnetic field through the sweep ensures that a closed bump is created along the chicane and no electron beam motion is seen globally around the storage ring.

Power Supply Controllers

All of Diamond's magnets are controlled by programmable power supplies [7]. These have the ability to play through a waveform stored in memory using a custom amplitude and time-step. All of these parameters, including the waveforms, can be configured from EPICS. The chicane magnets are programmed so that they have offset sine waveforms, shown in Fig. 2, for creating the 10 Hz bumps, and waveforms for ramping up, down, and degaussing.

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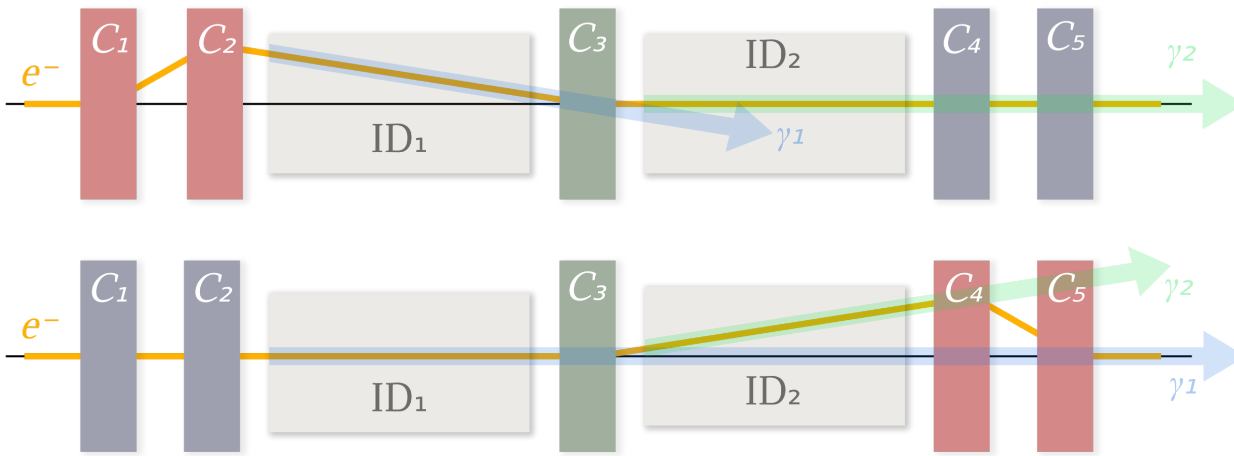

Figure 1: Schematic overview of I10 IDs and chicane magnets. Two extreme states of electron beam motion are shown. In the upper diagram the electron beam is bent by chicane magnets C_1 and C_2 such that it is steered off axis through ID_1. It is restored to the on axis trajectory by C_3 and travels through ID_2 producing photon beam γ_2 on axis. In the lower diagram we observe the other extreme state of the magnets. In this instance C_1 and C_2 provide no steering and the electron beam travels through ID_1 on axis, sending photon beam γ_1 down the beamline. C_3 kicks the beam and it passes it through ID_2 off axis, finally the electron beam's position and angle are restored to the nominal on axis trajectory by C_4 and C_5.

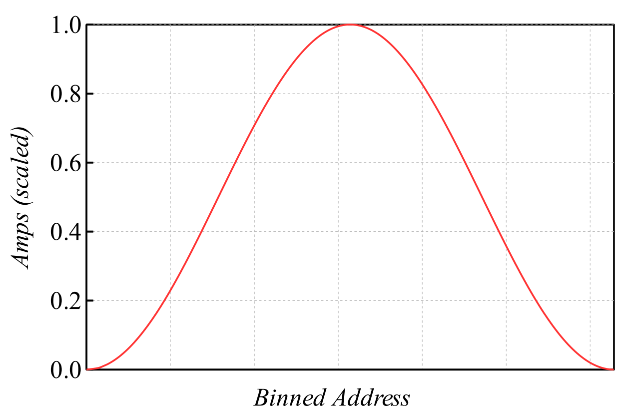

Figure 2: Offset sine wave trace used as the waveform in the power supply controllers. Using an offset prevents the supply from having to switch polarity which can potentially introduce switching noise.

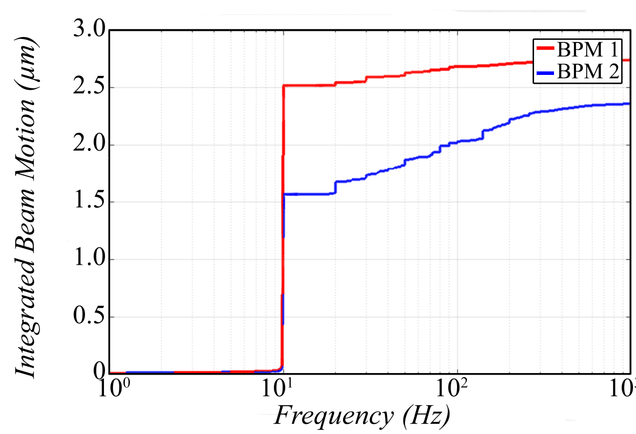

Figure 3: Integrated beam motion of two BPMs showing large amounts distortion at 10 Hz.

Timing Distribution

While the power supply controllers can accurately follow the desired set-point current very precisely it is also necessary to ensure the phase of the waveforms is accurate. To achieve this the power supplies have an optional event receiver module that allows triggering of the waveform pulse from a distributed timing signal. We are completely reliant on this event signal to phase the power supply controllers, as the controllers for each end of the chicane are located in geographically separate rack enclosures.

THE PROBLEM

Using the accelerator model nominal values can be found for the waveform amplitude and phasing delays can be set in the timing system fan-outs such that the pairs of chicanes are exactly 180°out of phase. Despite this when the chicane is switched on it contributes a significant 10 Hz component to the beam noise as the bump is not closed. We have a fast archiver that records a 10 kHz data stream from all beam position monitors (BPMs) which allows us to analyse beam motion in detail [8]. Using this fast archiver data to generate the integrated power spectrum shown in Fig. 3 it is clear that 10 Hz is a major source of beam noise.

CORRECTION ALGORITHM

We had already setup the machine to match the accelerator model, despite this the values chosen for our amplitudes or phases were not quite correct. As there are four AC magnets that need to have amplitude and phase configured (C_3 is a DC magnet, so has no phase information, and there is redundancy when solving the closed bump for a system of

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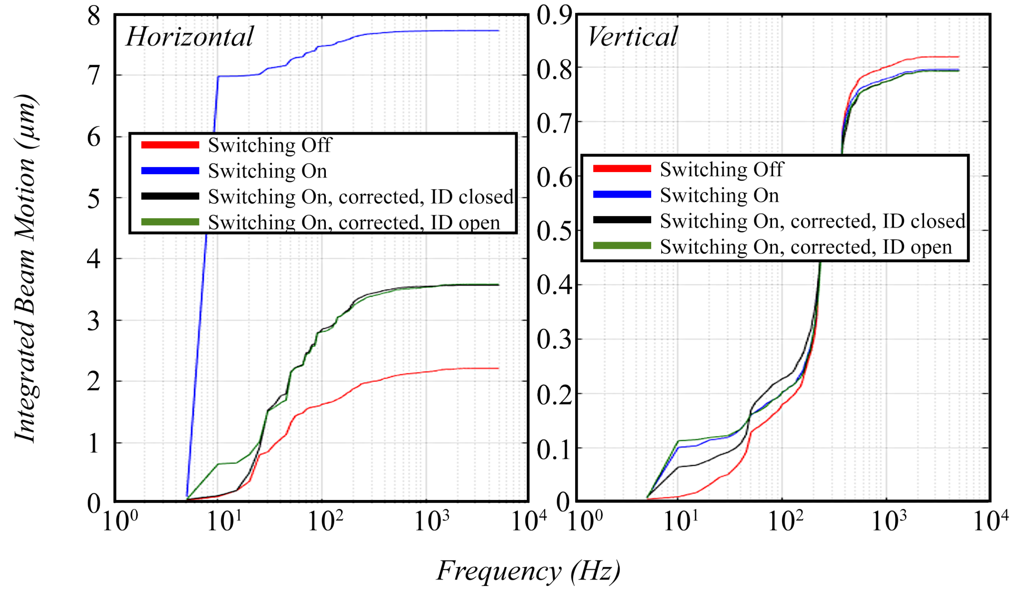

Figure 4: Horizontal and Vertical integrated beam motion for a single BPM. In the horizontal plane it can be seen that using the uncorrected I10 chicane creates a lot of motion at 10 Hz. The correction algorithm was run with the IDs at nominal user gap and completely recovers beam oscillations at 10 Hz. Moving the IDs away from the beam re-introduces some 10 Hz noise. The chicane contributes harmonics which provide increased noise above 10 Hz which we are not correcting. Note that we have no ability to control the vertical beam motion with the chicane magnets as they are designed to operate in the horizontal plane, but we do see an increase in motion in this plane.

five magnets so it is convenient to fix its amplitude anyway) the parameter space is large enough that it is implausible that a solution could be found by hand. As the amplitudes and phases of the magnets essentially form a system of linear equations we need a scheme that can modify the values based on a measured response matrix from the storage ring.

All steps in the correction algorithm are performed with the switching chicanes running. The first step is to measure the response matrix. We are only interested in disturbance at 10 Hz; we could use an FFT to separate out this part of the frequency spectrum, yet as we are only testing a single frequency it is more efficient to collect IQ data, with the added benefit that we can test waves at arbitrary frequencies instead of only ones which fit into our FFT bins. A vector of IQ data is taken for all horizontal BPMs simultaneously by recording a matrix X from time $t = [0, T]$, multiplying through by the complex exponential function, and taking the mean through time,

$$\bar{X}_{BPMs} = \left\langle X_{BPMs,\,T} \cdot e^{-2i\pi f t} \right\rangle ;$$

note that $\bar{X}_{BPMs}$ is a *complex* vector. Using these IQ vectors we can construct our matrix which maps chicane magnet amplitude changes into complex BPM values.

1. Measure a baseline vector $\boldsymbol{B}$ using the nominal amplitude set-points.
2. Step the amplitude of the first chicane magnet by a fixed amount a.
3. Measure a new vector $\boldsymbol{k}_1$ which represents the 10 Hz IQ data for the first kicker magnet. Return the chicane magnet to its nominal set-point.
4. Repeat steps 2 and 3 to generate $\boldsymbol{k}_2$, $\boldsymbol{k}_4$ and $\boldsymbol{k}_5$.
5. Build the response matrix,

$$M_{BPMs,\,Chic} = \begin{pmatrix} \frac{\boldsymbol{k}_1 - \boldsymbol{B}}{a} \\ \frac{\boldsymbol{k}_2 - \boldsymbol{B}}{a} \\ \frac{\boldsymbol{k}_4 - \boldsymbol{B}}{a} \\ \frac{\boldsymbol{k}_5 - \boldsymbol{B}}{a} \end{pmatrix} .$$

Our response matrix maps the changes in the chicane magnets to the 10 Hz BPM spectrum but we want to find the error from the residual 10Hz orbit error as recorded by all BPMs. For our non-square matrix we take the Moore–Penrose pseudo-inverse $\tilde{M}_{Chic,\,BPMs} = pinv(M_{BPMs,\,Chic})$ to invert the mapping. As our desired control point is for zero output on all BPMs the error vector is simply the residual BPM IQ vector recorded at 10 Hz. Forward multiplying the response matrix by this error vector $\boldsymbol{x}$ calculates the required delta for correction

$$\boldsymbol{y} = \overline{\boldsymbol{x} \cdot \tilde{M}},$$

where in this case the bar represents the complex conjugate. Now we can apply this correction to our accelerator; in order to subtract it from the existing state we must encode

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the current phase and amplitude into the complex plane, $q = Ae^{\phi}$, the correction is then $\boldsymbol{k} = q - \boldsymbol{y}$, with which we can determine our new kicker amplitudes $\boldsymbol{k}_A = abs(\boldsymbol{k})$, and phases $\boldsymbol{k}_\phi = arg(\boldsymbol{k})$.

Python is Diamond's standard scripting language [9]. It was used to implement the algorithm above and provide a command line interface so that the tool can be used without specialist knowledge. Extensive use was made of Numpy and of the BPM fast archiver libraries.

RESULTS OF THE SCHEME

The correction scheme was run during a machine development session. From Fig. 4 it can be seen that under ideal conditions it is able to completely correct 10 Hz beam motion in the horizontal plane.

Unfortunately we can not apply a single static correction that will remove the distortion under all cases, as when the ID gap is changed some motion returns. That the ID has this effect gives some insights as to why the machine model does not predict perfect values. Another observation from Fig. 4 shows that there is still considerable beam noise introduced at harmonics above 10 Hz, as well as in the vertical plane. It is not clear where these harmonics come from but it is possible they are generated in the interaction of the AC field with surrounding components.

FURTHER WORK

There are schemes that provide us with the ability to correct the non-linear aspects above, as well as correcting in the vertical plane. These have not yet been implemented due to the greater difficulty involved when compared to the linear scheme already discussed. The action of the fast orbit feedback [6] helps considerably in the vertical plane but does not entirely suppress noise. Corrector magnets in the arcs bordering the I10 straight could be integrated into a feed-forward scheme running on the fast orbit feedback controllers that uses the same timing trigger as the chicane magnets to play an additional correction that is locked in to the error signal.

For corrections to the horizontal plane it would be more convenient to suppress the harmonic noise at the source. As Diamond's power supply controllers use programmable waveforms these do not necessarily have to be sine waves. Using a similar scheme as detailed but calculating an FFT for each point in time, the amplitude of each point in the waveform could be set in turn.

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