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REDUCTION OF STORED BEAM OSCILLATIONS DURING INJECTION AT DIAMOND LIGHT SOURCE

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Abstract

At Diamond injection is performed by means a of a four kicker off-axis system, relying on a perfect timing and amplitude setting to produce a closed bump. Ageing of some of the kicker vessel components has progressively spoiled the performance of the system, causing oscillations in the stored beam.

Various schemes to control these oscillations have been considered including introducing an additional compensating kicker, and installing a non-linear injection kicker. Results of simulations analysing these schemes are presented, along with measurements taken in the storage ring using an existing pinger magnet. The effects of the reduction on the quality of beam seen by beamlines is also considered.

INTRODUCTION

Diamond uses a common injection scheme with a septum and four kicker bump. Ideally, these kickers produce a perfectly closed bump and therefore have no effect on the stored beam outside the injection region. In practice, it is very difficult to achieve this, leading to the stored beam receiving a kick which damps back down on a timescale of milliseconds, long enough for beamline users to see a noticeable impact on beam quality (Fig. 1).

Unfortunately, reducing the residual kick on the stored beam also has a detrimental effect on injection efficiency; although it is possible to reduce the residual motion to well below the level shown, this also reduces the injection efficiency to below the level allowed for top-up operation.

This problem has become more pronounced during operation at Diamond, which has been traced to problems with the titanium coating on the ceramic kicker vessels. Since the kickers have relatively long pulses across three turns, balancing the residual kick at every point is difficult. The reduction in dynamic aperture following installation of the DDBA upgrade [1, 2] has also made balancing residual kick and injection efficiency more difficult.

It was therefore considered to use a compensating kicker which can fire after the injection kickers and correct the residual error. Since the compensating magnet requires much a lower field, it can be fast enough to fire within a single turn, or possibly even a single bunch. In the absence of a suitable magnet in the Diamond ring, the effectiveness of such a scheme was tested using the existing diagnostics pinger magnets.

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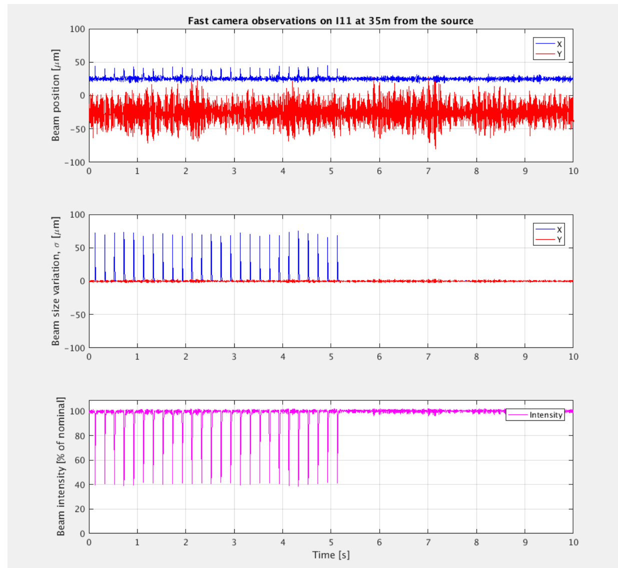

Figure 1: Ten seconds of data at the end of a top-up. The X-ray beam position (top), size (middle), and intensity (bottom) measured on a fast camera and fluorescent screen on the I11 beamline. The sample rate is 400Hz. The nominal X-ray beam size, σ, as measured by the camera is 160µm horizontally, 80µm vertically.

COMPENSATING KICKER

Simulations

We started by examining the turn by turn trajectories for different voltages at the kickers, as they come from data taken in the machine. These trajectories were fitted which allows to infer position and angle at every turn. By examining the (x, x') phase space turn-by-turn evolution at the pinger location in straight 23 we could identify the turn when the kicking pulse has to be imparted (x=0 crossing) and its intensity to zero the angle. Fig. 2 shows the large oscillations (grey) in the stored beam due to kickers operating at 2800A with an initial motion in x of about +/-2 mm.

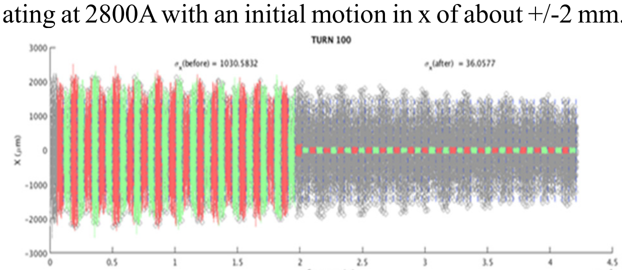

Figure 2: Simulated stored beam disturbance with and without correction.

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For the case shown here a kick of 152 μrad was suggested after the phase space analysis. However this assumes an ideal case where all the bunches receive the same kick within one turn (1.873 us). In the simulation we have modelled the pinger as a half-sine wave with a half period of 3μs. It was found that the pinger curve needs to be rescaled by a factor of 1.75 in order to effectively suppress the residual oscillations in the stored beam. Therefore in the case shown on Fig. 2, the actual imparted peak kick is 266 μrad, which gives a final peak-to-peak x of about +/- 85 um (oscillation reduction factor ~30).

Measurements

Stored beam oscillations can be measured in two ways in the Diamond storage ring. There are 173 BPMs which can give information on motion of the beam around the whole ring, but which are limited to turn-by-turn data and cannot see differing motion within the bunch train. Bunch-by-bunch motion can be seen using the pickup for the multibunch feedback (MBF) system, giving full data on centre-of-mass motion for all bunches at one point in the ring.

Figure 3 shows turn-by-turn data from a single BPM when the simulated horizontal pinger correction is applied in the machine. A significant reduction in oscillations at turn 60 (on an arbitrary scale) can be seen when the pinger is fired. This behaviour is replicated at all BPMs. Figure 4 shows bunch-by-bunch data for the same correction measured at the MBF pickup, showing that bunch motion is significantly reduced for all bunches, even though the pinger pulse is not optimised for this kind of correction.

ONLINE OPTIMISER

Theory

Single and multi-objective optimisation is a well-studied field. The Online Optimiser for Diamond Light Source (DLS-OO) [3,4] is a tool developed to implement a variety of optimisation functions in a modular fashion, including multi-objective genetic algorithm (MOGA, NSGA-II [5]), particle swarm (MOPSO) [6], simulated annealing (MOSA) [7], and artificial bee colony (MOABC) [8]. In addition to simulations, DLS-OO can also operate on any combination of EPICS PVs for both variable parameters and objectives. This allows the optimiser to work directly on the real machine, potentially bringing benefits in areas not easily simulated, or where discrepancies exist between model and real results.

One potential downside to online optimisation is the lack of parallelisation, since clearly the machine can only be in one state at a time. However, since tracking simulations can be much slower than measuring real data, it is not always clear which method will be faster in a given case. Another potentially time consuming issue is the risk of losing the stored beam if, for example, a magnet has its setpoint changed by too much.

All the optimisation algorithms have been tested previously on the Diamond storage ring, and it has been found that MOPSO generally provides the best combination of fast convergence and robustness.

Results With Pinger/IE

The best results for reduced residual kick were used as the starting point for optimisation using MOPSO. Initially parameters used were pinger timing and amplitude, with objectives peak-to-peak kick seen at diagnostic BPM in straight 23 and injection efficiency.

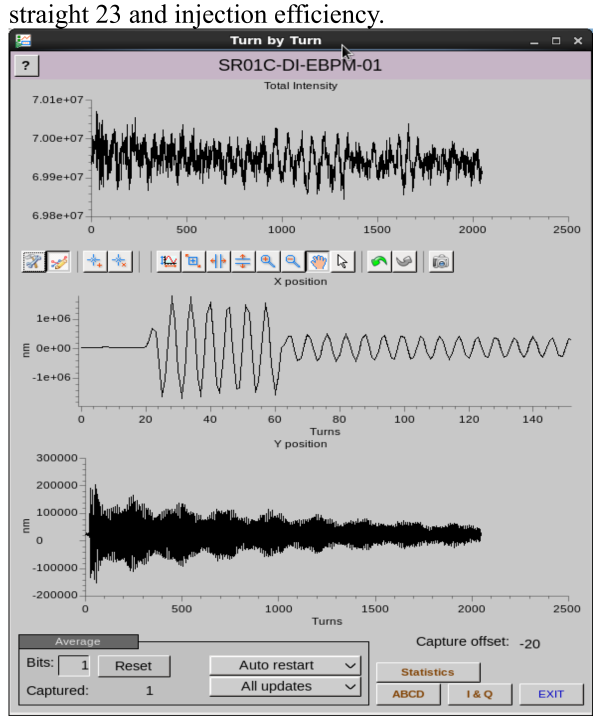

Figure 3: Turn-by-turn position at a BPM with injection kickers and horizontal pinger.

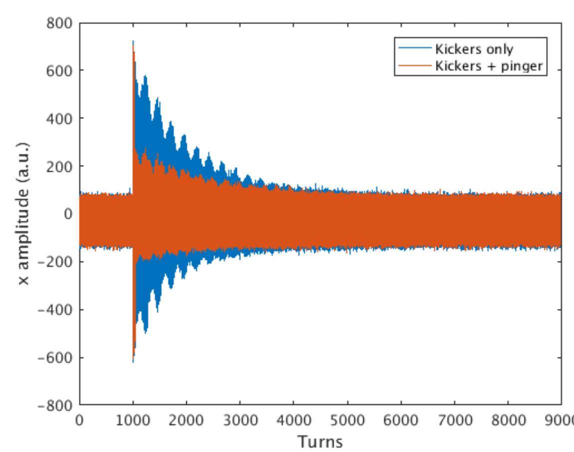

Figure 4: Horizontal bunch-by-bunch data with and without horizontal pinger.

Further studies were done including all four injection kicker amplitude and timing and the final two horizontal steerers in the booster-to-storage transfer line (BTS). This was much more time consuming since changes to the kickers are prone to lose the stored beam.

MBF data for the best result are shown in Fig. 5. Note that since the kickers were included in the optimisation, even the result with kickers only damps down much faster

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than shown earlier. Injection efficiency in these conditions above the minimum required to run top-up during user beam, but further work would be required to make this robust to varying conditions, especially ID gaps and wiggler fields.

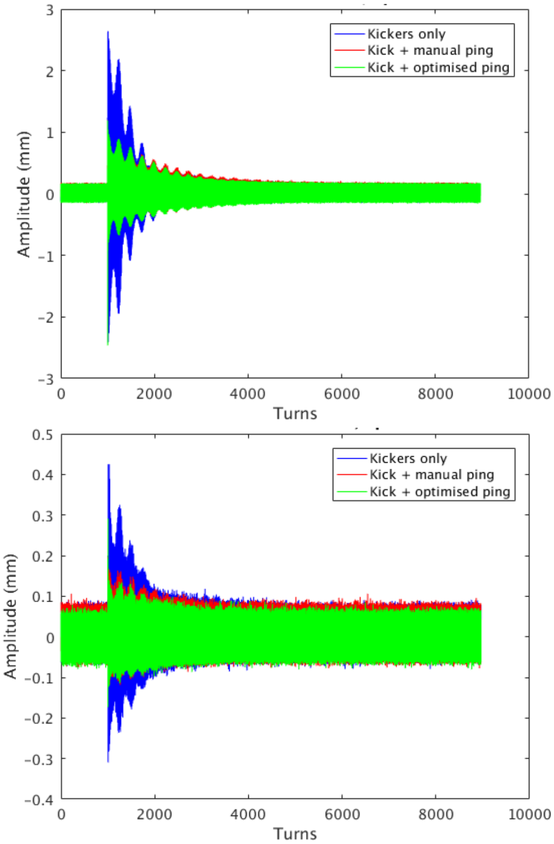

Figure 5: Comparison of bunch-by-bunch data with injection kickers, manually adjusted pingers, and pingers optimised using MOPSO. Top: horizontal, bottom: vertical.

BEAMLINES

Figure 6 shows data taken at the sample point of the I14 beamline. This shows intensity data from a 2D raster scan of a uniform sample acquired at 100 Hz at the sample point located about 185 m from the source point. Black spots show a drop in intensity of ~70% and lasting for 2-3 frames. The horizontal pinger reduces this to an almost negligible level at which the beamline would be happy to run. However, it remains to be understood why the vertical pinger magnet appears to make the effect worse for the beamline despite giving a clear improvement on the electron beam. No effect is visible from the septum magnet.

Intensity data sampled at 16 Hz and SAXS data taken at the sample point of the I22 beamline 47 m from the source point is shown in Fig. 7. Operating the kickers results in an intensity loss of ~8%, which is reduced to <2% by the pinger magnets. Again, there is no visible effect observed from the septum. This would likely be considered acceptable for all except very weakly scattering samples.

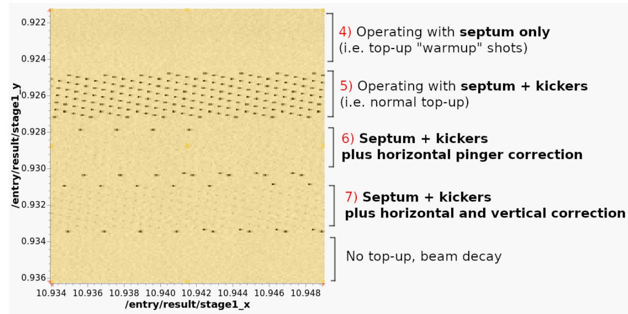

Figure 6: Intensity at sample point of I14 beamline for various kicker and correction settings.

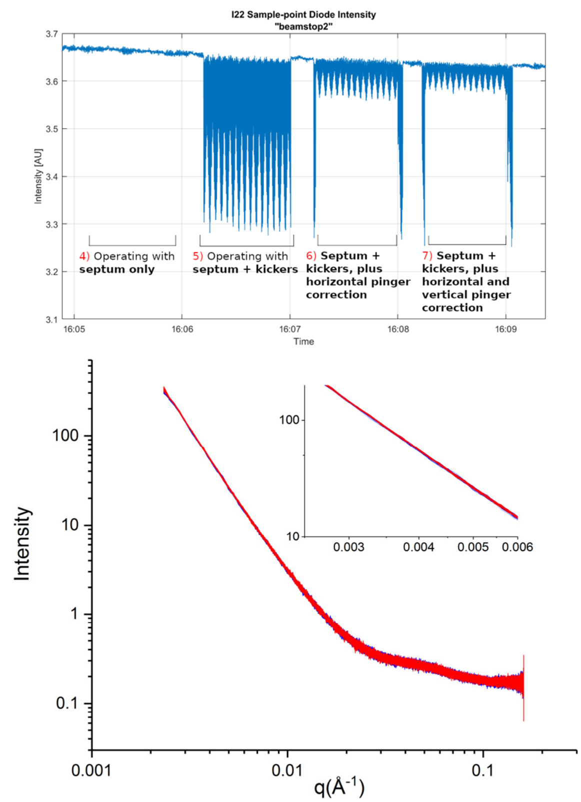

Figure 7: I22 results. Top: transmission diode intensity data with various magnet settings. Bottom: azimuthally integrated SAXS data from empty beamline, inset detail of low-q region. Red - no disturbance, blue - all injection magnets and both pingers.

CONCLUSION

An online optimiser can be used to find better machine setpoints in a live setting than can be achieved with simulations alone. The need for dedicated beam time and operational issues mean limited time is available for optimisation compared to simulations.

A fast corrector magnet can be used to compensate residual motion of the stored beam across entire bunch train during injection. A dedicated magnet would need to be installed for routine use, however, even the diagnostic pinger is able to produce good results. Initial measurements from a few beamlines are promising that this would bring real benefits to users. Further studies are ongoing to improve injection efficiency.

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