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OPERATIONAL USE OF PINGER MAGNETS TO COUNTER STORED BEAM OSCILLATIONS DURING INJECTION AT DIAMOND LIGHT SOURCE

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Abstract

Diamond uses a four kicker bump injection scheme. Due to a variety of factors it has become more difficult to perfectly match the four kicks while maintaining injection efficiency, resulting in some disturbance to the stored beam during top-up. This has consequences for beamlines which may see degraded beam quality during injections. A gating signal is provided, but this is not appropriate for all experiments, and in any case ideally would not be required. The disturbance to the stored beam can be partly controlled using the existing diagnostic pinger magnets installed in the storage ring. We present here a comparison of different compensation schemes and tests with beamlines, along with initial experiences operating during user beam time. Use of these magnet also provides proof of principle for any future, purpose-built compensation kickers.

INTRODUCTION

Diamond Light Source uses a four kicker bump injection scheme to inject into the storage ring. Ideally this would be transparent for the stored beam, but in practice some residual disturbance is present. There are thought to be two reasons for this. Firstly, there is some difficulty in exactly matching the pulse shape from the four kickers. Aside from the inherent difficulty, some issues with the titanium coating on the ceramic vessels may result in the field experienced by the beam not matching even if the power supplies are well matched. Secondly, the DDBA upgrade [1, 2] installed in 2016 reduced the dynamic aperture of the ring. This means a deliberate mismatch in the kickers is used to kick the injected beam within the aperture, but with some unwanted disturbance seen by the stored beam as well.

Since Diamond operates top-up on a 10 minute cycle during user beam, this oscillation is often visible to beamlines, usually as a drop in intensity since few beamlines are able to resolve turn-by-turn beam motion. A gating signal is provided so the disturbance can be avoided during data collection, but this is not always possible for longer experiments which may not be able to be paused. In any case, it would be preferable to eliminate this effect entirely.

We previously reported on the use of a diagnostic pinger magnet (PM) to reduce the disturbance on the stored beam [3]. We now present more comprehensive tests conducted with a wider variety of beamlines, and experience using this correction scheme during normal user operations at Diamond.

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PINGER CORRECTION

The PMs installed in Diamond are diagnostics magnets originally intended for dynamic aperture and frequency map measurements. The PMs produce a half-sine pulse of 3 μs, about two turns, in length. Turn-by-turn position data was measured in the ring, and simulations run to find the optimal amplitude and point in phase space to fire the PMs to reduce the beam motion (see Fig. 1).

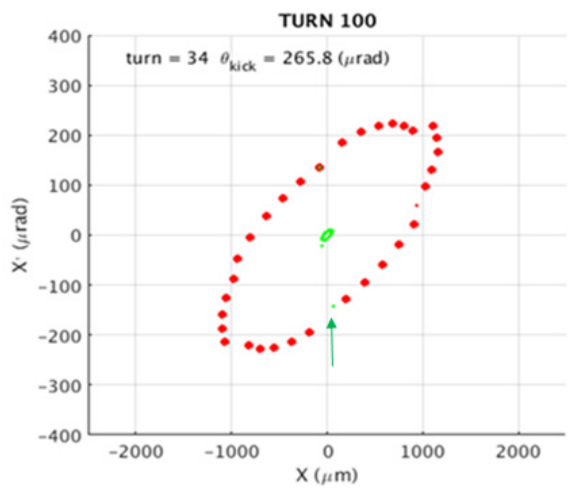

Figure 1: Measured bunch phase space (red) and simulated phase space after correction (green).

BEAMLINE TESTS

A selection of beamlines were involved in these tests, chosen for their range of different experiment and measurement techniques, and their ability to record data that is representative of the experience of real users. The beamlines used for these tests were I08, I09, I13, I18, I20 and B24.

The machine was first set up in standard user conditions, with 300 mA in 900 bunches. Sufficient time was allowed beforehand with standard top-up running to allow beamlines to reach thermal equilibrium before taking data.

A series of two test sequences were then run. For the first sequence, the injection magnets were fired continuously for 5 minutes, followed by 5 minutes each for a variety of different combinations of injection magnets and PMs, including different combinations of timing and amplitudes. The second test sequence used the same combinations of magnets, but instead firing continuously for 30 seconds, then off for 30 seconds, for 10 minutes in total for each set of magnets. Some correction schemes were repeated multiple times within each test, and time was allowed at the beginning and end to take data with no beam disturbance

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for comparison. The beam was refilled to 300 mA in between the two sequences. A summary of the first test sequence is shown in Table 1.

Table 1: Summary of First Test Sequence

Time	Mode
9:30-9.40	No disturbance
9.40-9.45	Injection magnets
9.45-9.50	Injection + H pinger
9.50-9.55	Injection + both pingers
9.55-10.00	Septum only
10.00-10.05	Injection magnets
10.05-10.10	Injection + H pinger
10.10-10.15	Injection + both pingers
10.15-10.20	Alternative kicker setting
10.20-10.30	**Re-inject to 300mA.**

Beamline I08

Beamline I08 took transmission images at 778 eV at the sample point, using a continuous raster scan over 30*30 mm (70*70 pixels) with a 10 ms/pixel exposure. Figure 2 shows intensity plots for measurements with no disturbance, injection magnets, and injection magnets plus both PMs. A drop in intensity (darker colours) when injection magnets are firing can be seen as diagonal lines in the middle plot. The drop in intensity when the injection kickers fire is reduced from 20% to 2% when using the PMs.

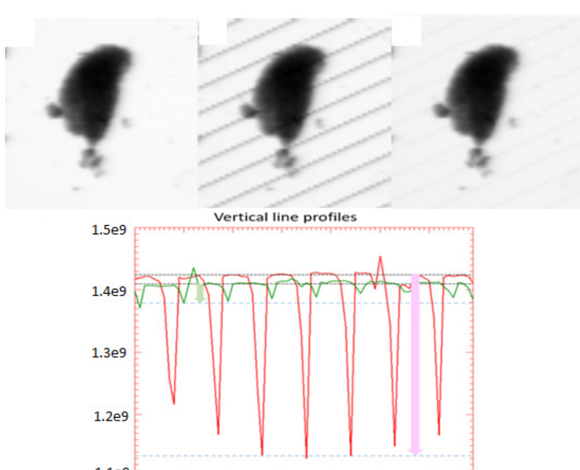

Figure 2: Top: Raster scans in I08 with no disturbance (left), injection magnets (middle), and both PMs (right). Bottom: Vertical slices through the middle (red) and right (green) plots.

Beamline I09

Beamline I09 took data for hard x-rays at their HEA detector and soft x-rays at the final mirror in the beamline optics. The results are shown in Fig. 3 for the schemes with no disturbance, injection magnets, horizontal PM, and both PMs. Intensity drop is reduced from 5% to 1% when using both PMs for compensation.

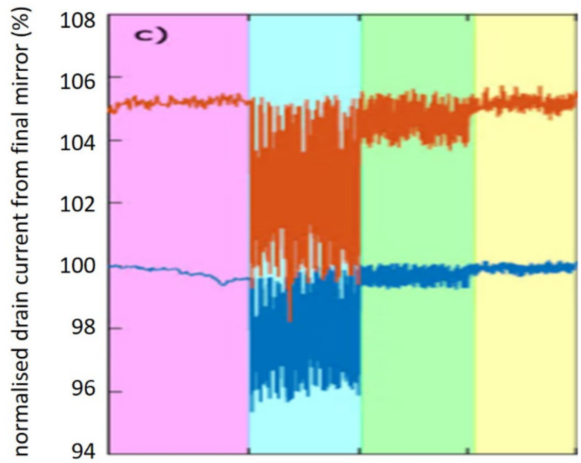

Figure 3: Intensity for hard (red, offset by +5%) and soft (blue) x-rays with no disturbance (left, pink), injection magnets only (centre-left, cyan), injection and horizontal PM (centre-right, green) and injection and both PMs (right, yellow).

Beamline I13

Beamline I13 measured image current on the last mirror in the beamline optics, giving a measure of photon beam intensity. The reduction in intensity due to the injection magnets can be clearly seen in the middle plot of Fig. 4. Using both PMs for compensation reduces the drop in intensity from 20% to 2%.

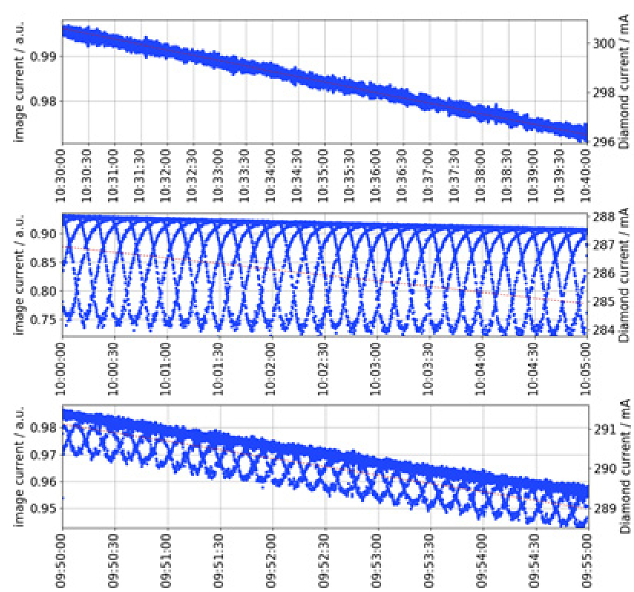

Figure 4: Image current at mirror with no disturbance (top), injection magnets only (middle) and injection magnets with both PMs (bottom).

Beamline I18

Beamline I18 measured an XRF map as the sum of all energy channels, using 0.01 second per point. Figure 5 shows a continuous scan during the full second test

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sequence. Darker colour indicates lower intensity. Use of both PMs helps mitigate the intensity drop, which is still visible to the beamline.

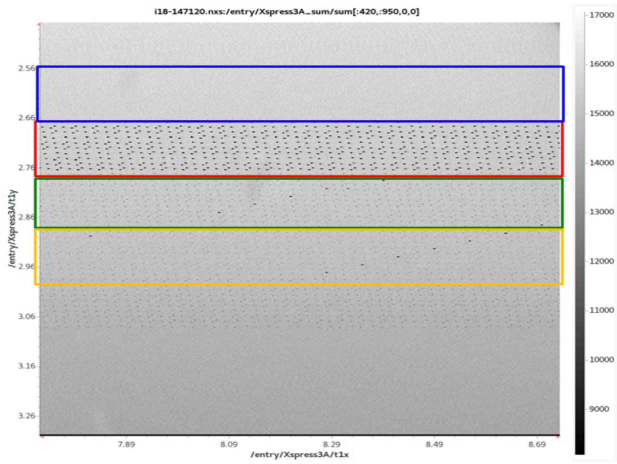

Figure 5: Intensity variation with no disturbance (blue), injection magnets (red), injection magnets and horizontal PM (green), injection magnets with both PMs (yellow).

Beamline I20

Beamline I20 took spectra through air at Cu K-edge (8979 eV). Time resolution was 9 µs per spectrum, with 20000 spectra taken for 180 ms total exposure time for each measurement. Intensity data for the schemes with injection magnets, and with both PMs were compared.

Analysis shows that the amplitude of the disturbance was reduced by a factor of 7, and the visible length of disturbance was reduced by a factor of 2, from 29.89 to 14.02 ms.

Beamline B24

Beamline B24 took data at the sample point using a single lysozyme crystal, collecting at a different position on the crystal for each test scheme. Data was taken at 12800 eV with a beam size of 7*7 µm with a 0.01 second exposure time and 900 frames for each point. The data was processed using their standard MX automated pipelines, with 4 methods for data integration and scaling, FastDP (blue), Xia2-3diii (red), Xia2-dials (green) and AutoProc (purple). The data metric plotted in Fig. 6 is low resolution Rmeas statistic, a lower number indicates less error in the data obtained.

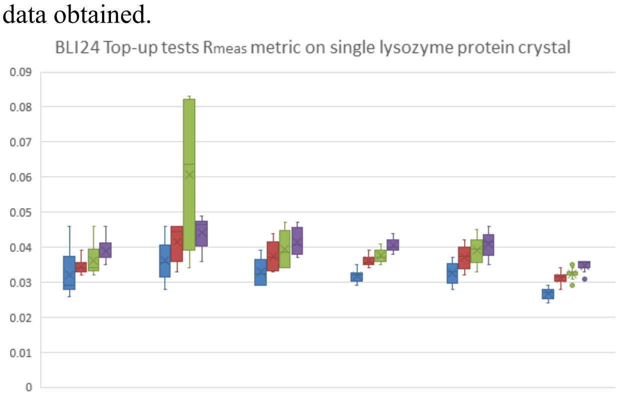

Figure 6: Rmeas statistic plotted for the various test schemes as indicated in Table 1.

Beam quality is best improved when using both PMs. However, this beamline appears sensitive to the effect of the septum magnet as well as the kickers, which the PMs are unable to correct. Also of note is that the Xia2-dials MX pipeline appears much more sensitive to the effects of the kickers.

USE DURING USER OPERATIONS

The results of testing showed potential benefits for many beamlines, and no reduction in beam quality for any. We therefore began operating the PMs during user beam in run 1, January 2020. Reduced operations due to Covid resulted in use of the PMs being discontinued in run 2. Although there were no issues with the PMs themselves, they represent an additional point of potential failure that might require more people to visit the site in person.

As operations began to be scaled back up, the PMs were used during user operation again in run 5, November 2020. We have now completed four user runs with the PMs operating during top-up. No faults or failures have occurred with the PMs or their power supplies.

Injection efficiency is reduced by 5-10% compared to operation without the PMs. Injection efficiency into the storage ring remains well above the level required by the top-up interlocks.

Residual disturbance to the stored beam, monitored continuously at a diagnostic BPM, remains consistent with no sign of drift or degradation since testing began, as shown in Fig. 7.

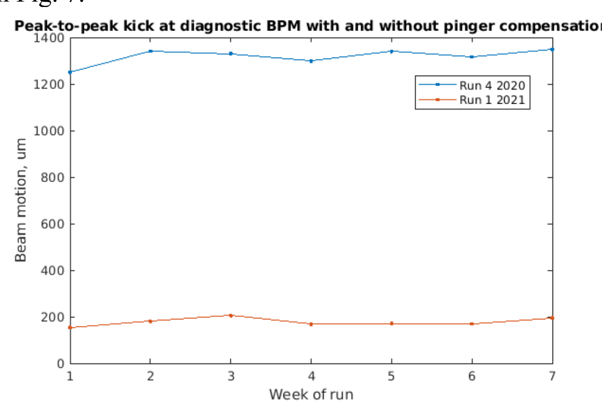

Figure 7: Peak-to-peak stored beam motion monitored over 7 weeks. Blue shows a run without PMs operating, red shows a run with PMs operating.

CONCLUSIONS

The diagnostic PMs installed in the Diamond storage ring can significantly reduce the disturbance to the stored beam seen by beamlines during top-up operations. While not originally intended to be used continuously in this manner, there have been no faults with the PMs, and no sign of any degradation in their effects.

Use of PMs is not intended as a permanent solution, rather serving as a testbed for future solutions that may include a dedicated correction magnet or use of the transverse multibunch feedback system to further reduce disturbance to the stored beam.

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