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INVESTIGATION ON MYSTERIOUS LONG-TERM ORBIT DRIFT AT NSLS-II*

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Abstract

Over a few months in 2018, we observed occasional episodes of relatively quick accumulation of correction strengths for the fast correctors (used by the fast orbit feedback) near Cell 4 (C04) region at NSLS-II Storage Ring. We immediately started investigating the problem, but the cause remained unclear. However, after coming back from the Fall shutdown, we experienced even faster drifts, at a rate of as much as 10 urad per day in terms of orbit kick angle accumulation. The risk of damage on the ring vacuum chambers by the continuing orbit drift without explanation eventually forced us to take emergency study shifts and temporarily lock out the C04 IVU beamline. After extensive investigation by many subsystem experts in Accelerator Division, ruling out many suspicious sources one by one, we were finally able to conclude the cause to be the localized ground motion induced by large temperature jumps of the utility tunnel right underneath the C04 straight section. We report the details of this incident.

INTRODUCTION

The National Synchrotron Light Source II (NSLS-II) is a 3-GeV third generation light source commissioned in 2014 at Brookhaven National Laboratory [1]. Currently the storage ring routinely operates at 400 mA beam current with top off injection, serving 23 ID beamlines. The ring consists of 30 alternating long (9.3 m) and short (6.6 m) straight sections, housing insertion devices, injection kickers, and RF cavities. In this paper, we describe the events and their root cause of mysterious large orbit drift we encountered during beamline operation periods in 2018 that eluded us for more than a month.

OBSERVATIONS OF ORBIT DRIFT

We noticed the first persistent orbit drift around the start of August 12, 2018, by the fact that the correction strengths of the fast correctors, which are automatically controlled by the fast orbit feedback (FOFB) system, were quickly accumulating. The fast correctors are rather weak, having the current range of +/-1 A with 12 urad/A. This forced us several times to run a shifting program that transfers the fast corrector correction strengths to the slow correctors, shown as the sawtooth behaviors of the maximum and minimum fast corrector strength history in Fig. 1. After about a week, the accumulation speed tapered down. The correction was always the strongest around Cell 4 (C04) straight section, and orbit analyses indicated a potential kick source around the same region. Since the readback for the insertion device (ID) orbit correctors for C04 ID was known to be unreliable, we decided to upgrade the power supply interface during the machine Fall shutdown starting on Aug. 20, 2018, to determine whether one of the ID correctors is the culprit if the same trend returns.

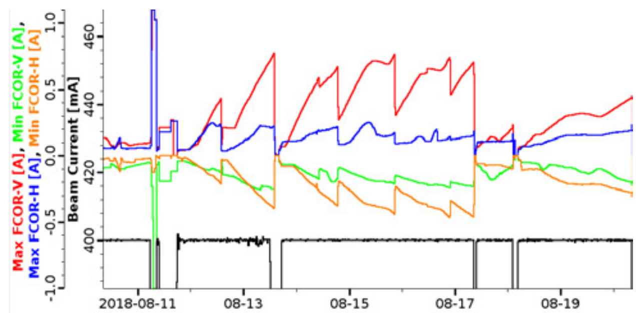

Figure 1: 10-day history of fast corrector max/min current, starting from August 10, 2018, before the shutdown.

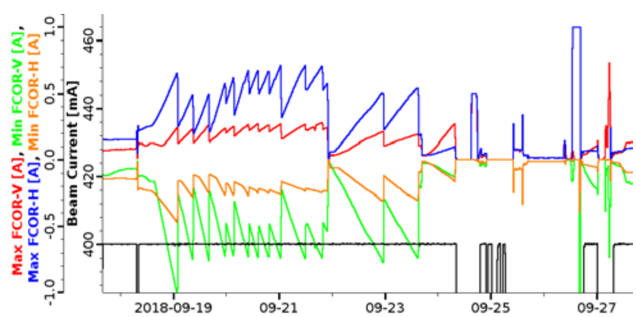

Figure 2: 10-day history of fast corrector max/min current, starting from September 17, 2018, after the shutdown.

When we came back from the shutdown on Sept. 17, 2018, the orbit was stable for one day, until a similar drift reappeared, as shown in Fig. 2. The strength accumulation was even faster than before, requiring more frequent fast-to-slow-corrector shifting operations.

During the course of the investigation, as shown in Fig. 3, we realized that our so-called ID BPM beam-based alignment (BBA) values were drifting by more than 150 um within a week, our administrative threshold value for resetting the ID BPM BBA values. We will discuss more about ID BPM BBA values later, but these values are supposed to be constant over a long duration and the basis of our active interlock system for equipment protection [2]. Hence, it was deemed too risky to continue operation of C04 ID without knowing why these values were varying this much.

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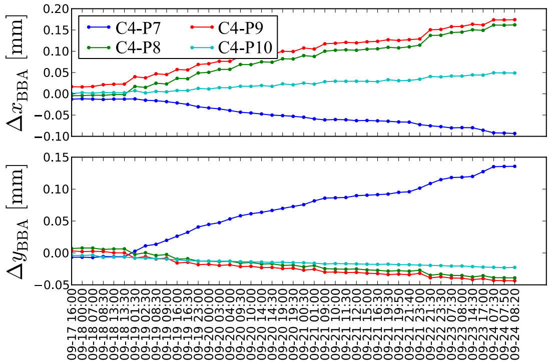

Figure 3: History of C04 ID BPM BBA deviation.

We started trying many tests to narrow down the cause while beamlines were still taking light, and kept investigating into the emergency beam study shifts after the beamline operation ended. Even though the initially suspected C04 ID correctors appeared stable according to the upgraded power supply monitoring and diagnostic tools, we turned them off at the rack to make sure no spurious kicks could be applied to the machine. The canting magnets in the straight were tested. All the magnet power supplies in the suspected region were thoroughly checked. All the motor amplifiers for the ID gap control were also turned off. To eliminate the possibility of malfunctioning BPMs included in FOFB driving this drift or an unexpected FOFB response, we tried different configurations of FOFB, to the point of completely turning off the feedback itself. Even with FOFB off, the orbit drifted at a rate of ~10 urad/day. This meant that some thing or things are kicking the beam within or very close to the straight in both planes, but we still could not find the source.

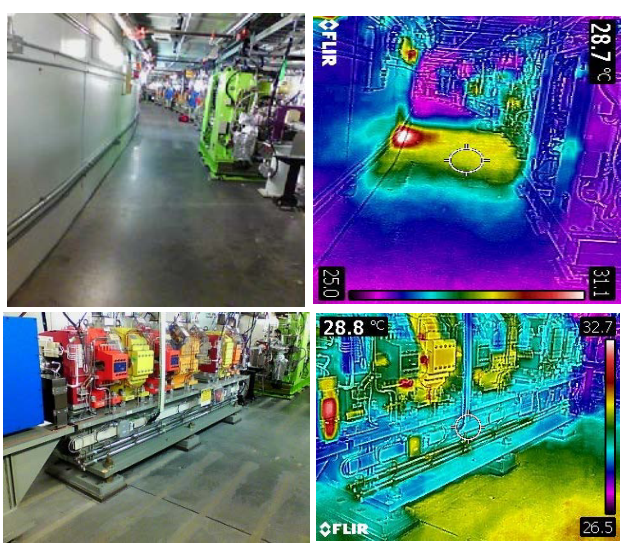

Figure 4: (Left) visible light and (right) infrared images of the section between C04 downstream bending magnet and C04 ID straight, right above the steam tunnel.

Finally, however, the girder alignment survey and thermal image scans of the C04 straight region on 09/26 revealed the root cause. As shown in Fig. 4, the floor temperature of C03 Girder 6, right next to and upstream of the straight section, was locally elevated. The typical floor temperature in the storage ring tunnel is 25-26 °C, while the hottest area in front of the C03G6 girder was 34 °C (measured with a hand-held IR thermometer). Although not known to many people at the time, under this girder was a steam tunnel that brings in hot water for the whole facility. The visible light and infrared images of the tunnel are shown in Fig. 5. Utility Group found that the belt for an exhaust fan in the tunnel was broken and fixed it on Sept. 18. According to the history shown on Fig. 6, the tunnel temperature was hovering around 150 °F when discovered. After the fix, the temperature dropped quickly to 110 °F within a few hours. This sudden change in temperature apparently set off the ground motion. Table 1 shows the girder motion around this region on 9/25/2018, compared to the survey data during Fall 2016. The fiducials moved as much as by 270 um (H) and 330 um (V).

Figure 5: (Left) visible light and (right) infrared images of the steam tunnel below the C04 ID straight.

Table 1: Survey Data Difference around C04 ID between Fall 2016 and Fall 2018

	Δx [mm]	Δy [mm]
C03G6-G1	+0.274	+0.176
C03G6-G2	+0.239	+0.127
C03G6-G3	+0.235	+0.072
C04 US BPM P7 Top 1	+0.109	+0.332
C04 MID BPM P9 Top 1	-0.122	-0.009
C04 DS BPM P10 Top 1	-0.031	+0.012

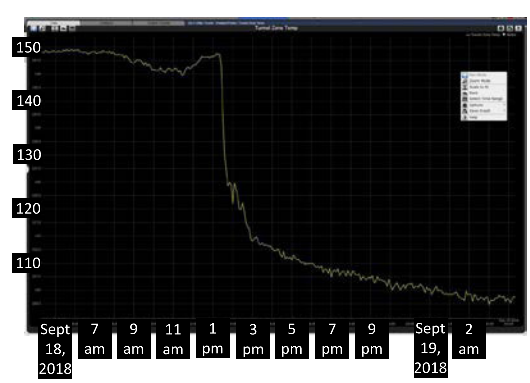

Figure 6: Steam tunnel temperature history on 09/18/2018 when the broken exhaust fan belt was found and fixed.

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The timing of the temperature drop and the onset of the fast corrector accumulation trend exactly matched. Looking back further, there was a sharp temperature rise near the end of Aug. 11, as shown in Fig. 7. This was probably when the fan failed, and responsible for the fast corrector drift before the shutdown. Note that the amount of temperature jump is smaller in the August event than in the September event, which corroborates well with the accumulation speed difference. As Fig. 8 shows, the tunnel temperature was gradually increasing since April, yet there was no discernable fast corrector trend. From this, we can infer that the gradual temperature change does not cause a fast large floor motion, but sudden change does.

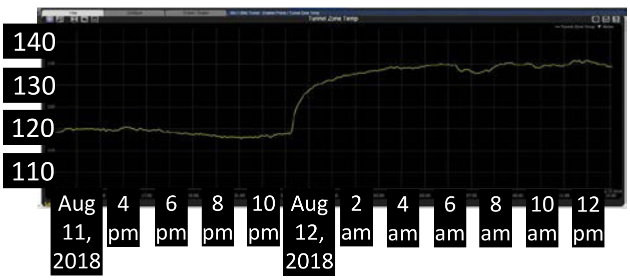

Figure 7: Steam tunnel temperature history in °F on 08/12 2018 when the exhaust fan belt apparently broke.

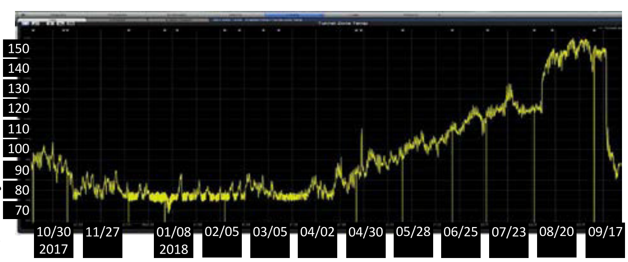

Figure 8: Steam tunnel temperature history in °F between October 2017 and September 2018.

Due to this girder motion, the 3 quadrupoles sitting on the girder must have moved, which created multiple dipole kicks, resulting in the orbit drift we observed.

The drifting of the C04 ID BPM BBA values shown in Fig. 3 can be also explained by this girder motion. The BBA values are defined such that, if added to the ID BPM raw position values, ID BPM positions will always lie on the straight orbit drawn between the position readings of the 2 nearest BPMs bounding the ID straight section. This definition corresponds to a special case of dynamically-bounded orbit (DBO) as defined in [3], where the orbit at the 2 bounding BPMs is adjusted to their quadrupole-scan-based BBA values and the IDs in this bounded region are all fully open.

The most important characteristic of this orbit is that it stays constant as long as the 2 bounding BPMs and those within the bounded region, i.e., ID BPMs, are not physically moving and there is no change in transverse kicks within the bounded region. If the orbit is not constant as was the case in this incident, at least one BPM must be moving or the kick angle by one magnetic element must be changing. In this case, as Fig. 9 shows, one of the bounding BPMs (C3-P6) and one of the ID BPMs (C4-P7), located right above the steam tunnel, must have been moving. The rest of the ID BPMs (C4-P8, C4-P9, C4-P10) are located on a different concrete slab to the right of the black seam (along the white dotted line). Using the unique characteristic of ID BPM BBA, combined with the reasonable assumption that C4-P9, C4-P10 and C4-P1 were much less affected by this thermal event, we can estimate the physical motion of C3-P6 and C4-P7 since the last ID BPM BBA update (within a week), by fitting a straight line to the 3 BPM positions, extending it to P6 and P7, and calculating deviations. The estimated result is shown in Fig. 10.

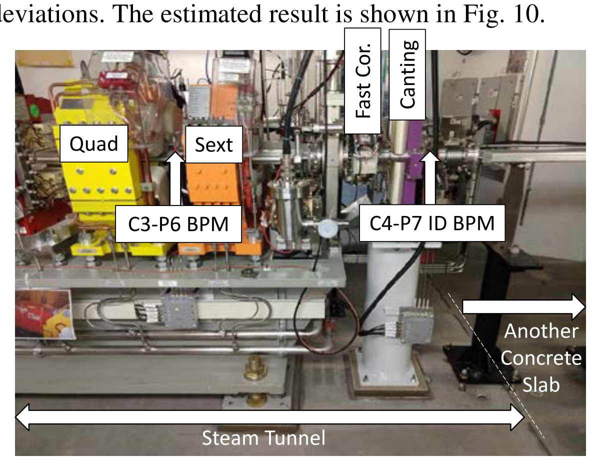

Figure 9: Relative positions of one ID BPM (C4-P7), one bounding BPM (C3-P6), different types of magnets, and the steam tunnel (extending beyond the left edge and separated by 635-mm-thick accelerator tunnel concrete floor). C04 ID is located on the right side of photo.

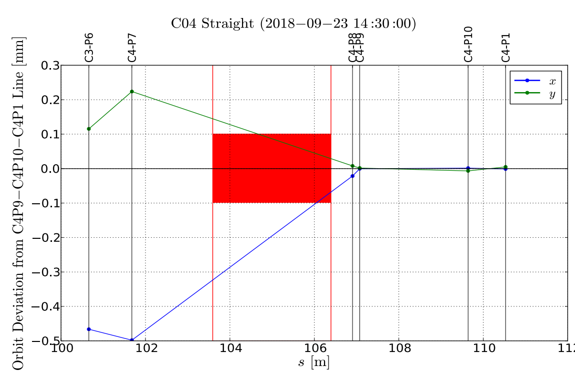

Figure 10: Estimated physical BPM motions for C3-P6 and C4-P7 assuming C4-P9, C4-P10 and C4-P1 were stable (C04 ID represented by red box).

CONCLUSION

The puzzling orbit drifts observed at NSLS-II during 2018 was found to be caused by the floor motion due to the temperature swings of the steam tunnel underneath Cell 3 Girder 6, right next to Cell 4 ID straight. The resulting girder motion led to quadrupole displacements, generating gradually increasing dipole kicks, to which FOFB reacted to compensate. At the same time, multiple nearby BPMs were also physically moving. This incident taught us the importance of good communication among different groups as well as having tunnel floor temperature measurements near the special locations such as tunnels.

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