ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAF010

FAST GLITCH DETECTION OF COUPLED BUNCH INSTABILITIES AND ORBIT MOTIONS *

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Abstract

During high current operation at NSLS-II storage ring, vertical beam size spikes have been noticed. The spikes are believed due to ion instability associates with vacuum activities localized in the ring. A new tool has been developed using gated BPM turn-by-turn (TBT) data to detect beam centroid glitches. When one turn orbit deviates outside the predefined window, a global event will be generated. This allows synchronized data acquisition of TBT beam positions around the ring. Bunch by bunch data is acquired at the same time to analyze the possible coupled bunch instabilities (CBI). Besides CBI mainly due to ion bursts, fast orbit glitches have been captured with the new tool. Sources of the glitches can be identified.

MOTIVATION

Modern storage rings operate at high current and low emittance, deliver high brightness beam to the science experiments. Various feedback systems are typically implemented to suppress the instabilities: orbit feedback to suppress beam motion up to several hundred Hertz; bunch by bunch (BxB) feedback to suppress coupled bunch instabilities (CBI) etc. With high current stored in the storage ring, there are unpredictable instabilities observed. These instabilities may come from vacuum bursts or dust trapping, which cause lifetime drop or even beam dumps. Observations at other facilities have been reported for example in [1,2]. Sometimes the instability sources are not easy to be identified without suitable diagnostic tools.

During NSLS-II user operation, beam size spikes have been noticed on the two X-ray diagnostic beamlines [3]. Typical NSLS-II machine parameters and achieved performance have been reported in [4,5]. Figure 1 gives an example with spikes captured during 325mA top off operation. The pinhole cameras had exposure time ~10ms and image was updated at ~10Hz rate.

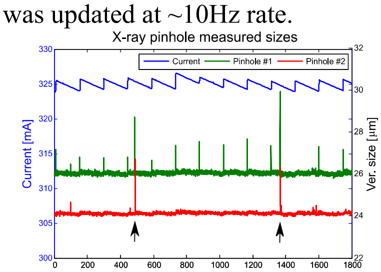

Figure 1: Vertical beam size spikes observed during top off user operation. Top off injection disturbance was observed at Pinhole #1 (Green). Two large spikes (arrow locations) were detected on both pinhole cameras in-between injections.

By investigating the archived vacuum pressure data, some of the spikes are able to be aligned with the vacuum activities localized in the ring. This makes us think the spikes are likely due to ion instability from vacuum activities. Beam centroid and/or sizes may be affected within a short period of time (less than 1ms for centroid motion as BxB feedback ON, sizes blowup ~10ms).

To further study the vertical size spikes and understand fast transient beam motions, fast glitch detection methods have been proposed and tested with a new FPGA firmware. The primary method is to check the BPM TBT data in real time, if the position goes beyond the programmable threshold, a global event can be generated to capture the global BPM TBT (378kHz) and fast acquisition (FA, 10kHz) data. Meanwhile, power supply 10kHz data, RF cavity field data can be saved to track the possible sources. Data was saved to the same post-mortem (PM) buffers [6,7]. Separately, the fast transient of bunch to bunch motions can be captured from BxB feedback system. Other instruments like oscilloscope or spectrum analyzer can be externally triggered to further debug the beam signals at glitch.

An FFT spectrum analyzer has also be used to monitor the BxB feedback driving (or pickup) signal spectrum. Whenever the beam CBI happens, BxB feedback system will react and accordingly, the correcting signal will be increased. The FFT spectrum analyzer can be configured to trigger whenever the feedback correcting signal goes above the predefined window in the selected frequency range. Similar threshold detection can be implemented inside the BxB feedback controller [8].

IMPLEMENTATION

Similar to the FA glitch detection function which has been implemented [7,9] at NSLS-II active interlock (AI) system, the fast glitch detection utilizes the BPM TBT data. A new FPGA firmware is implemented at dedicated BPMs with the new function. The algorithm compares the real-time TBT position data with a predefined window, in case the position goes outside the window, a glitch signal is generated. The signal is then fed to AI system so that a global event is broadcasted and PM data can be saved at glitch occurrence. In most cases when glitches were detected, beam was disturbed without current loss, PM data is captured before/after the glitch trigger so that beam positions, power supply (main fast correctors) and RF cavity field can be further analyzed.

Due to unclosed bump of the injection kickers, stored beam sees pulse kick effect at top-off injections. The disturbed bunch centroid can typically be suppressed within 100 turns, however, it will still be larger enough to

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trig a glitch. An injection inhibit function has been added to ignore this kind of regular/predictable disturbance, so that randomly happening glitches can be registered. Figure 2 shows a schematic of the fast glitch detection and injection inhibit function, where the blue dots represent the BPM measured TBT position data with one randomly happening outlier (red circle) and one predictable outlier (green diamond). The two outliers go beyond the threshold window (black dash lines) and report two glitches. There is an inhibit window (~1000 turns) with width and delay adjustable. In case the glitch event falls in the inhibit window like the green one, the glitch event will not be broadcasted. Otherwise, the glitch generates a global event (red glitch). To disable the glitch detection at injection, the inhibit window delay is adjusted so that it starts ~10 turns prior to injection kicker triggers.

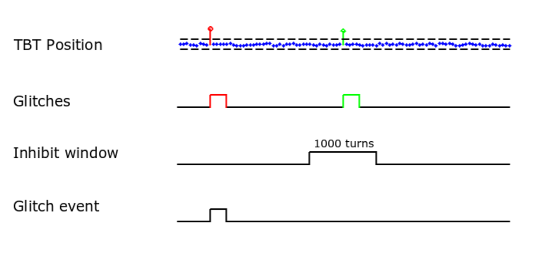

Figure 2: Illustration of fast glitch detection and its inhibit functionality. A 1000 turns inhibit window masks predictable disturbance like the injection transient.

BPM gate function [10,11] can be enabled to detect the fast CBI. Depends on the type of instabilities, bunch to bunch oscillates at different phases, TBT data processing all stored bunches in the ring may not detect the CBI. A proper gate ensures proper detection of ion instabilities which typically cause motions around 10MHz range at NSLS-II storage ring.

The glitch detection has also be realized using the BxB feedback system. Typically the spikes related to ion instability are accomplished by transverse CBI, BxB feedback signal will react accordingly. An FFT spectrum analyzer has been configured to monitor the feedback kick signal and is triggered with frequency mask [12]. A local trigger signal can be generated when the correction signal goes above the mask. In principle the frequency domain generated trigger signal can be distributed globally, similar to the BPM measured glitches.

BEAM MEASUREMENTS

With the fast glitch detection function implemented, there are several types of fast transient motions being captured. The first type is the ion instability related to vacuum burst, as seen in the Fig. 1 example. Betatron oscillations are observed, lasting for ~100 turns. Vertical size spikes are usually noticed at the X-ray pinhole camera at the same time. The second type is fast orbit disturbance, lasting for ~5000 turns. Other fast transient observations include the short period of synchrotron oscillations etc. We further discuss the ion instabilities and orbit glitches here.

Ion Instability Due to Vacuum Burst

As discussed in the motivation section, the main purpose of developing the fast glitch detection is to have a better understanding of the vertical sizes spikes. With the technique implemented in the dedicated BPMs, ion instabilities have been observed during high current operations. Figure 3 gives one of such glitches captured. In this particular example, vertical TBT position went beyond the 20μm threshold (shown as red dashed lines) and a global trigger event was generated at turn #0. Vertical turn to turn position has peak deviation of ~40 μm, there was ~10 μm horizontal orbit disturbance. The machine was running in top-off mode at 350mA and a vertical size spike was captured at the same time. BxB feedback data was saved at the glitch as well. Mode analysis of the BxB data reveals ion frequency hump around several MHz (mode # -20), as shown in Figure 4. This is a typical ion instability which has been detailed discussed in [13].

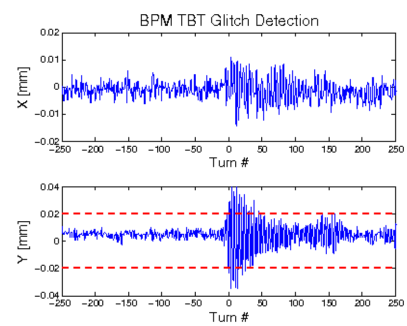

Figure 3: BPM TBT data captured with the fast glitch technique, X/Y are horizontal/vertical positions. A global trigger event was distributed at turn #0 where vertical position went outside the threshold of 20μm (red dashed lines).

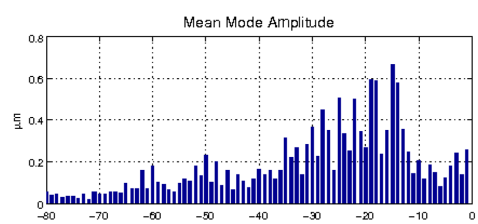

Figure 4: Unstable modes analyzed from the BxB feedback data saved at the glitch.

Due to BxB feedback, beam centroid disturbance was able to be suppressed within a short period of time (~100 turns), the beam size was blown up and takes longer time (~10ms) to damp down similar to previously measured after pulse kick [14]. Also, it will be interesting to switch off the BxB feedback for ~1ms when a glitch is detected, allowing large dipole oscillation to grow [15]. This may be helpful to diagnose the ion species and localize the ions. A gated camera set up at the newly constructed X-ray pinhole beamline [3] is available now to measure the fast profiles at glitch event.

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FFT spectrum analyzer with frequency mask trigger has captured the ion instabilities as well. Figure 5 measures the BxB feedback kicking signal real-time spectrum. At a fast ion glitch, the signal saw spikes as the feedback system respond to the betatron motions. The center frequency was set to ~13.5MHz where the ion frequency hump was detected. The comb shape was the response of bandpass FIR filter used in the feedback, with notches at revolution frequency and its harmonics.

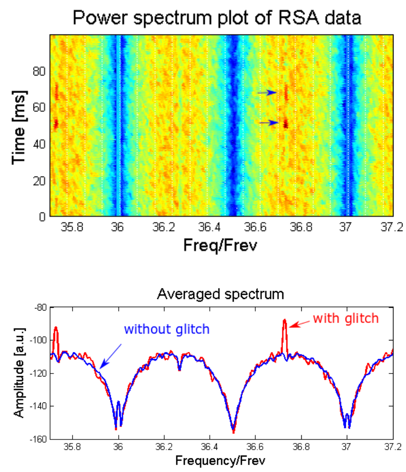

Figure 5: (top) FFT spectrum captured at fast ion glitches, around 50ms and 70ms where arrows point. (bottom) averaged spectrum with and w/o glitches.

Fast Orbit Glitch Detection

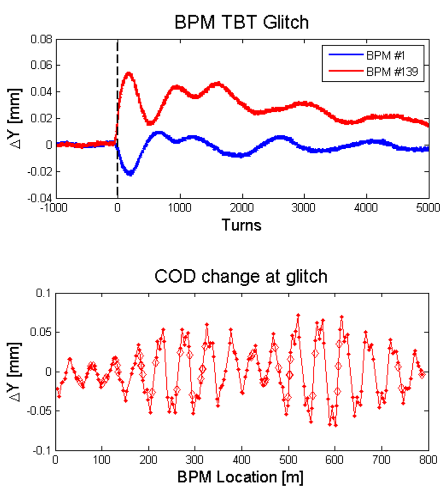

Figure 6: (top) TBT vertical position measured at the glitch showing orbit disturbance; (bottom) COD from synchronized BPM data around the ring.

In addition to the ion instabilities, orbit disturbance has been noticed using the glitch detection tool. Figure 6 gives one of such orbit disturbance. With the same 20μm vertical thresholds, a glitch event was registered when TBT position went beyond at turn #0. Different to the fast betatron motion observed in Figure 3, this time there was no CBI observed. Instead, the beam orbit was affected for about 10ms and eventually corrected back, as the fast orbit feedback was ON. The plot shows two BPMs (#1 and #139) in the ring. As synchronized BPM data around the ring is available at the glitch, global closed orbit difference (COD) can be plotted. The bottom plot in the figure is the COD at peak disturbance (~ turn #200) compared to the undisturbed orbit.

Besides the vacuum burst caused fast ion instabilities and orbit disturbance, the glitch detection function has been able to capture other fast transient motions. We will not expand the discussion here.

Source Identification

It will be desired to identify or localize the root cause of fast transient motions. Due to the complication of feedback systems, while glitches were captured, accurate identification of the source(s) might be not as easy.

For the ion burst instabilities shown in Figure 3, turn to turn orbit difference for the entire ring BPMs has been used together with the diagonal response matrix, to determine the possible vacuum burst locations. The method seems promising even with several microns of turn to turn orbit difference. Additionally, BxB feedback can be gated OFF for short period of time (~ms) at glitches, this way betatron oscillation will grow larger and hopefully, source(s) can be better identified.

For the fast orbit disturbance, as shown in Figure 6, sources can be localized by using the COD and inverse orbit response matrix. In the meantime, BPM TBT/FA data, cell controller (CC) [16] FA data and power supply FA data are all saved at the glitch. With further investigation of the synchronized data, we conclude that most of the orbit glitches seen as of now are due to large spike position reading from the cell control. The issue has been discussed in [7,8] to address the active interlock. In case the spiked FA data is used for fast orbit feedback, it will cause orbit disturbance at the level of 50 microns. In the example of Figure 6, BPM #139 had one FA data point spikes to -16.78mm noticed on the cell controls. Fast correctors respond right after that and glitch was registered.

We plan to upgrade the CC firmware, to handle better the FA spike data so that orbit will not be affected.

SUMMARY

A fast glitch detection technique has been proposed and implemented at NSLS-II storage ring BPM. Using the new technique, fast ion burst due to vacuum activity has been observed and analyzed. Vacuum burst location can possibly be localized with the synchronized turn to turn orbit disturbance. The ion instability was able to be detected by the BxB feedback correcting signals.

Short period orbit disturbance has been noticed with the glitch detection tool. At the glitch, synchronized data saved at BPM, CC, and power supply can be used to identify the sources. We conclude some of the orbit glitches are due to CC jitters. A future upgrade of the CC firmware will address the issue accordingly.

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The authors thank coordination and diagnostic groups in supporting the implementation of the glitch detection function. Control room operators helped during glitch data collection.

REFERENCES

[1] U. Wienands, "Vacuum Performance and Beam Lifetime in the PEP-II Storage Rings", in *Proc* Particle Accelerator Conference 2001 (PAC'2001) Chicago, Illinois, June 2001

[2] Y. Tanimoto, T. Honda, S. Sakanaka, "Experimental demonstration and visual observation of dust trapping in an electron storage ring", PRST-AB 12, 110702 (2009)

[3] W. Cheng, *et. al.*, " Improvements of NSLS-II X-ray Diagnostic Beamlines", presented at the 9th Int. Particle Accelerator Conf. (IPAC'18), Vancouver, Canada, Apr.-May 2018, paper WEPAF012 , this conference.

[4] F.J. Willeke, "Commissioning of NSLS-II", in *Proc. 6th International Particle Accelerator Conference*, Richmond, VA, USA, paper MOYGB3, pp. 11-16,

[5] W.X. Cheng, *et al.,* "Characterization of NSLS2 Storage Ring Beam Orbit Stability", in *Proc. 4th International Beam Instrumentation Conference*, Melbourne, Australia, September 2015, paper THALA02, pp. 625-629,

[6] G.M. Wang et al., "NSLS-II Post Mortem Function Development and Data Analysis of Beam Dump", in Proc. North American Particle Accelerator Conf. (NAPAC'16), Chicago, IL, USA, Oct. 2016, paper WEPOB66, pp. 1039-1041

[7] K. Ha et al., "NSLS-II Active Interlock System and Post-Mortem Architecture", in Proc. 7th Int. Particle Accelerator Conf. (IPAC'16), Busan, Korea, May 2016, paper THPOY048, pp. 4214-4216,

[8] D. Teytelman, private communication

[9] S. Seletskiy, J. Choi, K. Ha, and R.M. Smith, "Upgrade of NSLS-II Active Interlock System", in Proc. 7th Int. Particle Accelerator Conf. (IPAC'16), Busan, Korea, May 2016, paper THPOY023, pp. 4140-4142,

[10] W. Cheng, Y. Li, K. Ha, "Techniques for Transparent Lattice Measurement and Correction" J. Phys.: Conf. Ser. 874 012082 (2017)

[11] Y. Li, W. Cheng, K. Ha, R. Rainer, "Transparent lattice characterization with gated turn-by-turn data of diagnostic bunch train", PRAB 20, 112802 (2017)

[12] Spectrum Analyzers RSA3000B Series https://www.tek.com/datasheet/rsa3000b-series

[13] W. Cheng, Y. Li, B. Podobedov, "Experimental evidence of ion-induced instabilities in the NSLS-II storage ring", Nucl. Instr. and Meth. A861 (2017) 38–45

[14] W.X. Cheng, B. Bacha, Y. Li, O. Singh, and Y. Tian, "Beam Stability During Top Off Operation at NSLS-II Storage Ring", in Proc. North American Particle Accelerator Conf. (NAPAC'16), Chicago, IL, USA, Oct. 2016, paper TUPOA71, pp. 425-427

[15] W. Cheng, *et. al.*, " Developments of Bunch by bunch Feedback System at NSLS-II Storage Ring", presented at the 9th Int. Particle Accelerator Conf. (IPAC'18), Vancouver, Canada, Apr.-May 2018, paper WEPAF012 , this conference.

[16] Y. Tian, *et. al.*, "NSLS-II Fast Orbit Feedback System", ICALEPCS'2015