BEAM STABILITY DURING TOP OFF OPERATION AT NSLS-II STORAGE RING*

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Abstract

NSLS-II storage ring started top off operation since Oct 2015. User operation current has been gradually increased to 250mA. Observations of beam stabilities during top-off operations will be presented. Total beam current was typically maintained within +/-0.5% and bunch to bunch current variation was less than 20%. Injection transition during top-off was measured with bunch by bunch (BxB) digitizer, and BPM to analyze the orbit motion at various bandwidths (turn by turn, 10kHz and 10Hz rate). Coupled bunch unstable motions were monitored. As the vacuum pressure improves, fast-ion instability is not as severe compared to early stage of commissioning /operation, but still observed as the dominant instability. Resistive wall instability is noticed as more in-vacuum-undulator (IVU) gaps closed. xBPM measured photon stability and electron beam stability at top off injection have been evaluated. Short term and long term orbit stabilities will be reported.

TOP OFF OPERATION STATUS

NSLS2 is a newly constructed synchrotron light source with electron energy of 3GeV, emittance of 1nm.rad/8pmrad (H/V). The storage ring circumference is ~792m with 30 DBA cells. Three damping wigglers are available symmetrically to decrease the horizontal emittance below 1nm.rad. NSLS-II storage ring has been commissioned in 2014 and start user operation in 2015. Top off operation has been realized since October 2015. User operation current has been gradually increased to the current level of 250mA.

Typical lifetime during 250mA is ~10 hours, top off injection period of 140 seconds maintains the total beam current within +/-0.5%. Bunch to bunch current is measured on the fill pattern monitor [1]. As shown in Fig. 1 is the typical fill pattern during 250mA operation. A long bunch train with 2ns bunch separation was filled followed by the ion cleaning gap. There is a single bunch filled in the gap to continuous monitoring the tune. Ignore the rise edge, bunch to bunch current variation is within 20%.

Fill pattern monitor scope was triggered at top-off injection and 100 turns of data were saved. The trigger delay was adjusted to have first 33 turns before the injecting beam arrives. Top image in Fig. 1 shows the fill pattern before and after injection. About 100 bunches coming from injector were filled at target bucket #648. Total beam current increased by ~1.1mA for this particular injection.

NSLS-II in-house developed digital BPM electronics is capable to measure the beam positions in turn by turn (TbT, 378kHz for NSLS-II storage ring), fast acquisition (FA, 10kHz) and slow acquisition (SA, 10Hz rate) mode. The waveform data can be synchronized with the injection trigger to see the position transient due to mismatch of pulse kickers.

As the injection kicker pulse is short, different bunches may see different kick amplitude. Ideally if the four injection kickers are perfectly matched, the stored beam will be bumped locally in the injection section. However, it's not possible to match the four kicker pulses perfectly and each bunch may see different kicking amplitude, even outside the injection bump. To see the bunch to bunch position oscillation due to the injection mismatch, bunch by bunch feedback system data can be used. Coupled bunch stability can be analyzed using bunch by bunch data. To cross check and calibrate the bunch by bunch feedback measured positions, a 20GHz sampling rate scope has been used to sample the four button broadband signals and process the bunch to bunch positions. The bunch to bunch diagnostic tools are very useful to study the injection mismatch, as well as other advanced beam measurement like bunch to bunch tune measurement.

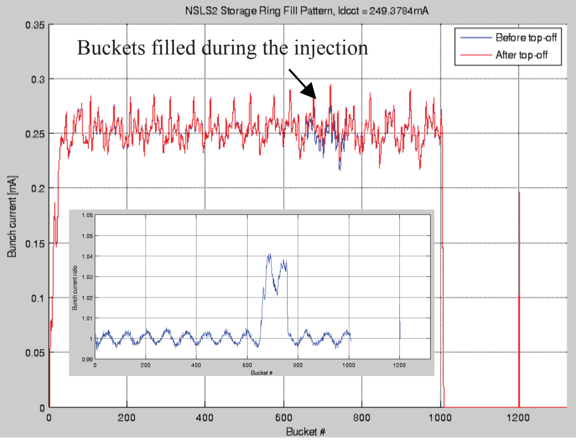

Figure 1: Fill pattern during 250mA top off injection. 100 bunches were injected at target bucket #648-750. The image shows the fill pattern before (blue) and after (red) the injection. Embedded image shows the bucket current change in percentage. ~3% current on top of 0.25mA was filled at the target bunches.

BUNCH BY BUNCH POSITION MONITOR

Bunch by bunch feedback system has been in operation since early stage of the storage ring commissioning [2]. The system proves to be critical to suppress the transverse coupled bunch instability as well as single bunch TMCI instability. The digitizer sampled ADC values is determined by the bunch position and bunch current, it will be affected if the bunch phase changed relative to the detection phase and front end electronics attenuator settings.

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All these factors require calibration to get the real bunch position information. To minimize the dedicated beam time for calibration, a 20GHz scope has been configured to detect the A/B/C/D four button signals. Interpolation method, as discussed in fill pattern monitor paper [1], has been used to determine the bunch signal strength of four buttons. Bunch positions can be calculated use the traditional Δ/Σ method. Scope BPM and horizontal transverse bunch by bunch BPM have the same beta function, so that feedback digitized data can be directly calibrated with the scope measured positions.

Figure 2 gives the scope measured bunch to bunch position during the same top off injection as Fig. 1. Beam was filled at target bucket #648. The scope was externally triggered with the top off injection, trigger delay was adjusted so that there are 33 turns before the pulse kickers were fired and injecting beam arrived. Turn #34 is the first turn at injection. There are 100 turns data saved.

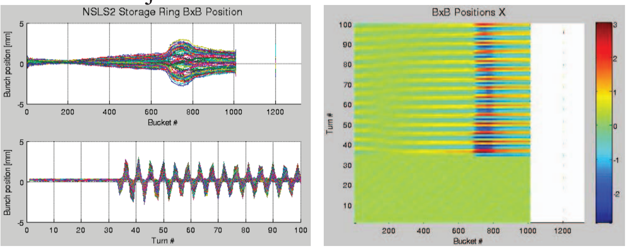

Figure 2: Bunch by bunch position measured from a 20GHz scope, sampling the A/B/C/D broadband button signals.

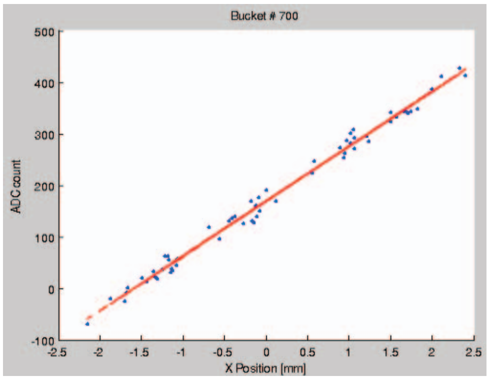

Figure 3: Calibration of feedback ADC readings with respect to the scope measured bunch positions during top off injection.

Injecting buckets saw larger turn to turn position oscillation due to the pulse kicker mismatch. Assume the lattice is well corrected, BPM at scope and feedback should see same amplitude of oscillation after the injection kick. Comparing the scope position data and feedback digitizer acquired data, it's convenient to calibrate the feedback ADC/mm/mA. Fig. 3 gives the slope fitting of feedback ADC readings with respect to the position measured using scope. Result of bunch #700 was plotted in the figure, with bunch current ~0.2375mA. Averaging for all the bunches, the feedback digitizer calibration factor came out to be 460.5 ADC/mm/mA.

INJECTION TRANSIENT

NSLS-II BPM electronics can acquire TbT, FA and SA data. Benefit from the event timing system, all the BPMs can be synchronized triggered with the injecting kick to study the transient effect. More information of the NSLS-II digital BPM developments and performance can be found in previous papers [3-5].

Figure 4 is a typical TbT position oscillation after the top off injection. BPM trigger delay was adjusted to have turn #4 as the first turn after kick. As can be seen from the BPM SUM signal, it increased by 0.42% which means a total beam current increase of 1.05mA, this agrees with the DCCT measurement. Depends on the beta-function at the BPM location, oscillation amplitude varies. From Fig. 2, turn by turn positions can be averaged from bunch by bunch position for all the bunches, the result agrees with the BPM measured turn by turn position while taking in to account the beta function at the pickups.

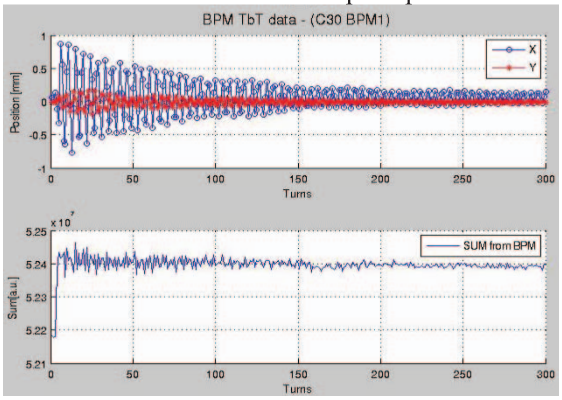

Figure 4: BPM turn by turn position transient during top-off operation. BPM SUM signal shows a ~0.42% increase which is corresponding to 1.05mA beam captured.

As can be seen from the figure, dipole oscillations measured with BPMs are suppressed quickly. This is due to fast damping of bunch by bunch feedback system. At top off injection, bunch by bunch feedback system can be switched OFF for ~10ms to study the injection transient with synchrotron radiation damping and chromatic damping. It is useful to measure the unstable coupled bunch instabilites with similar method.

Even though the dipole motions can be suppressed within 200 turns, it's interesting to study how the beam size behaves during top off injection. With recent upgrade to the x-ray pinhole diagnostic beamline, one can measure a good image with short exposure time. During dedicated machine study shift, 120 bunches were filled in the ring to 33mA so that the charge per bunch is similar to 250mA user operation. Pulse kickers (pinger) were used to displace the beam within one turn and measure the dipole motion and beam sizes with various delays after the kick. Bunch by bunch feedback was ON or with 20ms OFF to see the damping effect difference. Figure 5 shows the result with horizontal pinger kicking the beam at 0.25kV, horizontal bunch by bunch was switched OFF for 20ms for this example. BPM TbT data shows that beam centroid were damped down within 5ms, however, the x-ray pinhole camera measured beam sizes decay in longer time. The decay time is close to the radiation damping time of 23ms. From these measurements, it's likely that beam filamented in phase space quickly after the pulse kick, bunch centroid was able to be suppressed by feedback or chromatic damping, beam sizes will damp down by radiation only. A fast gated camera is under consideration which will make the turn by turn beam profile measurement possible using the x-ray pinhole diagnostic beamline.

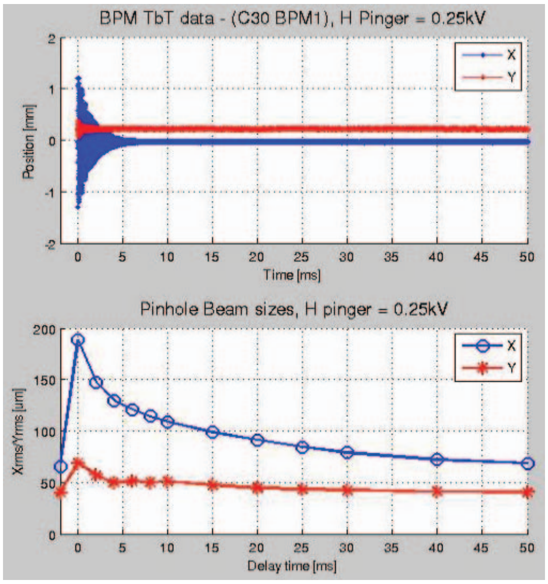

Figure 5: Measured beam centroid (BPM TbT) and beam sizes (X-ray pinhole) after pulse kick. Pinhole images were saved with different delay to the pulse kick. Exposure time was at 2ms.

STORED BEAM STABILITY

Fast ion instability have been considered and experimentally confirmed as the dominant transverse coupled bunch instabilities [6]. The ion instability is not as severe as the vacuum pressure improves, it's still observed as the fastest unstable sources with feedback grow/damp measurement. As more and more insertion devices installed and in operation, the resistive wall instability can be observed if the feedback was switched OFF long enough but beam was not lost. As the ion instability tends to saturate although the ion instability has fast growth time. Resistive wall instability appears at low frequency with slower rate but grows exponentially. Transverse feedback system is capable to cure the dipole unstable motions up to highest achieved beam current of 400mA. There are longitudinal coupled bunch instabilities observed at high current studies.

Besides the typical operation lattice of +2/+2 Chromaticity, high Chromaticity lattice of +7/+7 has been tested during machine studies. High chromaticity helps to cure the dipole unstable modes combined with the bunch by bunch feedback system. Fast ion caused instabilities are still detectable with vertical feedback OFF for 20ms. Further studies will be helpful to determine the optimized chromaticity working together with the feedback, taking in to consideration beam lifetime and injection efficiency.

Orbit stability has been discussed in previous paper [5] when the machine was operated in decay mode. There was not much difference on the electron beam orbit stability in top off operation mode, although constant beam current will help the beamline optics thermal load. Short term orbit stability is maintained to be within 10% of beam sizes with fast orbit feedback. Long term orbit stability has been checked during operation. Horizontal orbit sees daily drift pattern at dispersion BPMs which is due to the earth tide effect. Ring circumference is believed to be changed by ~30um due to the gravity of moon and sun. More recent studies reveal that vertical orbit has daily drifts more than 10 microns even with orbit feedback ON. The drift is considered to be some noise source near C16. Fast orbit feedback is responding as expected. Fig. 6 shows the vertical orbit long term stability during 50 hours un-interrupted top off operation. During studies when the orbit feedback was turned OFF, vertical orbit drifts as large as 150um were measured. We are actively investigating the orbit drifts sources and working on the solutions.

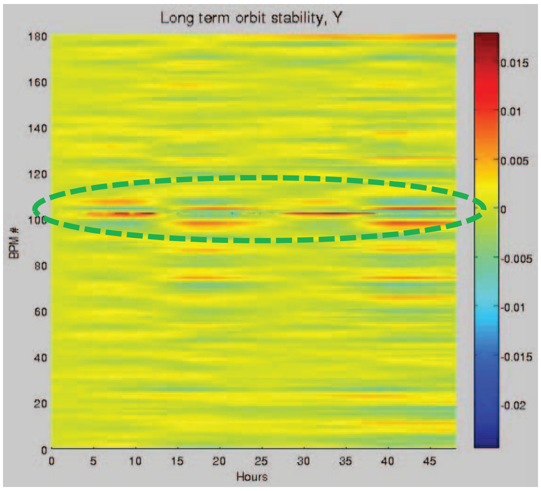

Figure 6: Long term vertical orbit stability. Large orbit drifts were observed near BPM #100, marked with green dash line oval.

REFERENCES

[1] W. Cheng et al., "NSLS2 Fill Pattern Monitor and Control", in Proc. IBIC'2015, Melbourne, Australia, September 2015.

[2] W. Cheng et al., "Commissioning of Bunch-by-bunch Feedback System for NSLS2 Storage Ring", in Proc. IBIC'2014, Monterey, California, USA, September 2014.

[3] K. Vetter et al., "NSLS-II RF Beam Position Monitor", PAC'2011, New York, NY, USA, March 2011.

[4] J. Mead "NSLS-II RF Beam Position Monitor Commissioning Update", in Proc. IBIC'2014, Monterey, California, USA, September 2014.

[5] W. Cheng et al., "Characterization of NSLS2 Storage Ring Beam Orbit Stability", IBIC'2015, Melbourne, Australia, September 2015.

[6] W. Cheng et al., "Observation of Ion-induced Instabilities at NSLS2 Storage Ring", in Proc. IBIC'2015, Melbourne, Australia, September 2015.