COMMISSIONING OF BUNCH-BY-BUNCH FEEDBACK SYSTEM FOR NSLS2 STORAGE RING*

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Abstract

Transverse bunch by bunch feedback system has been designed to cure the coupled bunch instabilities, caused by HOM, resistive wall or ions. The system has been constructed, tested and commissioned with beam. Preliminary studies show that the feedback system can suppress single bunch instability as well as coupled bunch instabilities. Mode analysis of the unstable coupled bunch motion reveals fast ion instability exist even at relative low current.

INTRODUCTION

As the newest third-generation light source, NSLS2 at Brookhaven National Laboratory has been constructed and commissioned recently. 50mA stored beam has been achieved without insertion devices [1]. Insertion devices commissioning and user operation will follow in the near future. NSLS2 storage ring will have < 1nm.rad horizontal emittance by using weak dipoles together with damping wigglers. For the storage ring of 792m circumference, geometric impedance, resistive wall impedance and ion effects are expected to be significant. A transverse bunch-by-bunch feedback system has been designed to suppress the coupled bunch instabilities. More information can be found in previous papers [2,3].

Pickup signals for transverse feedback system are coming from button BPMs. Broadband RF front end electronics detect the bunch to bunch positions separated by 2ns, which is then digitized and processed to get the correction signal. The correction signal can be precisely timed to act on the individual bunches come back in one turn. Dimtel's iGp12 digitizer [4] was selected for NSLS2 bunch by bunch feedback. It has EPICS driver and graphical operation panel integrated and other diagnostic features like bunch cleaning, transfer function measurement and others.

High power amplifiers from Amplifier Research are fully controlled through LAN/RS232 gateway remotely. Amplifier gain, forward power, reverse power and other status can be monitored/controlled from the CSS panel. There are temperature sensors installed on the stripline kicker feed-throughs and chambers. These RTD's temperature data will supply health information of the kicker, especially when the machine is running at high current.

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KICKER PERFORMANCE

As the feedback actuator, stripline kicker was designed to have sufficient high shunt impedance and minimized beam impedance. The stripline kicker has two 30cm long plates housed in round chamber with inner radius ~ 39mm. The chamber inner surface and plates are copper coated. Each plate was fed by a 500W broadband amplifier though 1/2'' Heliax cables.

Figure 1 shows one assembled stripline kicker and its TDR measurement result. Between the cursors were the 30cm (1ns) plate. The plate was matched to 50 Ohm. The dip was coming from vacuum feedthrough ceramic seal.

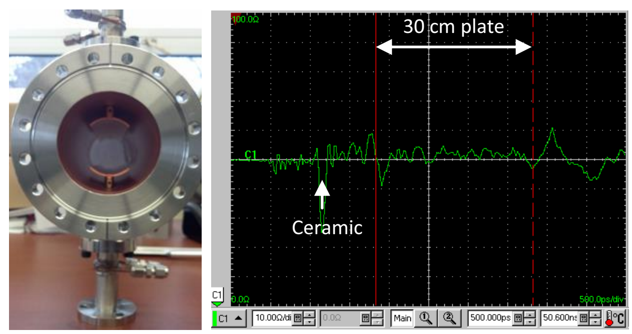

Figure 1: Assembled Stripline kicker (left) and TDR measurement response (right).

Installed stripline frequency response, together with high power amplifier, long Heliax cables and 500W attenuator, were measured using network analyzer, as shown in Fig. 2. In the working frequency range of 0-250 MHz, gain flatness is about 3dB. Phase response is less than 5 degrees difference in the range.

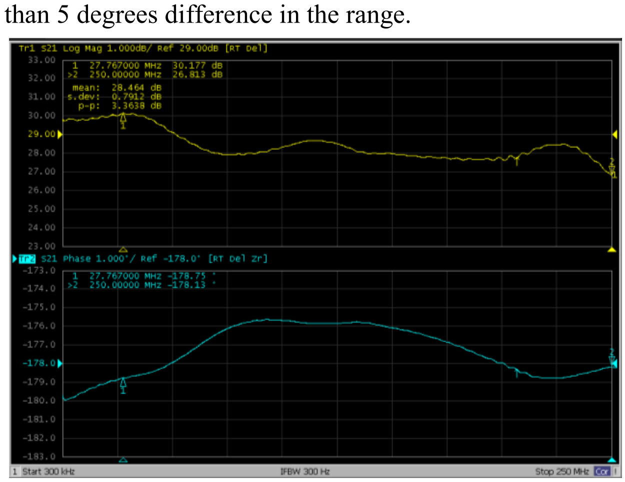

Figure 2: Network analyzer measured amplitude and phase response, including high power amplifier, stripline kicker, Heliax cables and attenuator.

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CURE BUNCH INSTABILITIES

Single bunch instability was observed at around 0.7mA. Vertically beam was getting unstable at higher single bunch current. About 1mA threshold current was measured for normal +2/+2 chromaticity. This instability was observed with normal conducting 7-cell PETRA-III cavity [5], as well as super conducting single cell cavity. Measuring the transfer function at different single bunch current reveals that vertical instability happened when the vertical betatron sideband met the low sideband (likely -fs sideband). Shown in Fig. 3, are the transfer function measurement results at various single bunch current. As the current increasing, horizontal betatron frequency didn't change much, while the vertical betatron peak moved towards lower frequency and eventually met the smaller peak at ~ 84.3 kHz.

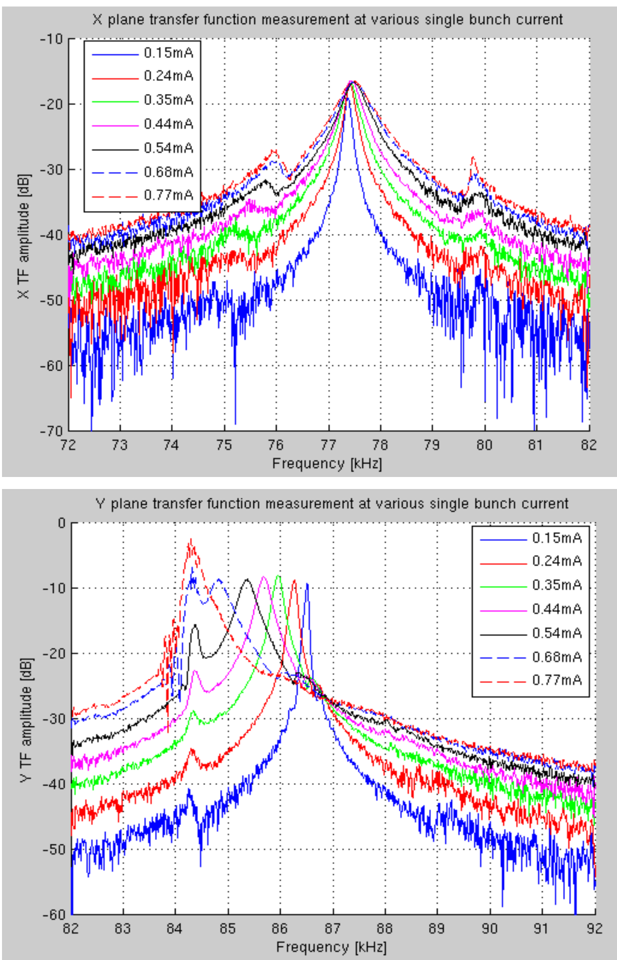

Figure 3: Single bunch transfer function measurement at various bunch current for horizontal (top) and vertical (bottom) plane.

It's an interesting observation that 3dB bandwidth of the transfer function was increasing as the single bunch current increased. Determined from the Fig. 3 spectrum, Fig. 4 plots the peak frequency and 3dB bandwidth change at different bunch current. Horizontally the tune peak didn't vary much with the current. Vertically tune decreased at higher single bunch current, the slope was fitted to be -2.92 kHz/mA (or fraction tune v_y slope of 0.0077/mA). This agrees with the results measured with other methods [1]. Besides the peak drift, from the transfer function measurement, one can see that 3dB bandwidth was increasing linearly with single bunch current. This indicates the incoherent tune spread in the bunch was increased at higher single bunch current.

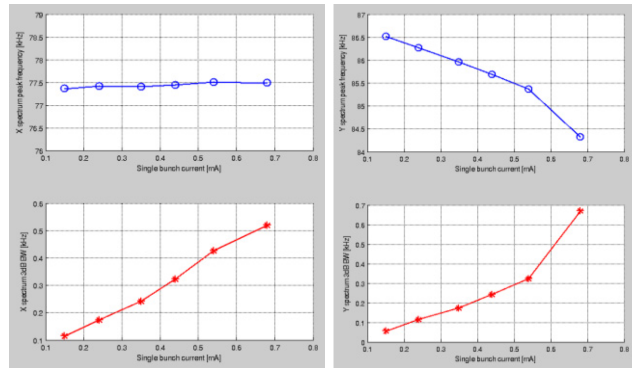

Figure 4: Transfer function spectrum peak frequency and 3dB bandwith change at different single bunch current.

After optimizing the transverse feedback loop parameters, the loop was first closed in single bunch mode. Vertical single bunch instability was suppressed and more than 6mA can be stored in one bunch, until the vacuum pressure elevated and sent out alarms.

In multi-bunch fill, when the stored beam was above 20mA, coupled bunch instabilities were observed. These instabilities are considered to be ion related. The feedback system was able to suppress them in both x/y planes. Figure. 5 shows the BPM turn by turn position and its spectrum with and without feedback. The data was recorded at 44mA stored in ~1040 buckets. Note that bunch to bunch current varies. Without transverse bunch by bunch feedback, beam centroid RMS motion was about 11 um for both planes. Turning on the feedback helped suppress the betatron oscillations. As can be seen on the power spectrum density plots, betatron sidebands were suppressed by more than 60 dB. Beam RMS motion was about 6.3um horizontally and 2.6um vertically. Horizontal motion was higher due to longitudinal energy jittering coupled through dispersion. The integrated lower frequency motions were 1.2/1.9 um RMS (<1 kHz).

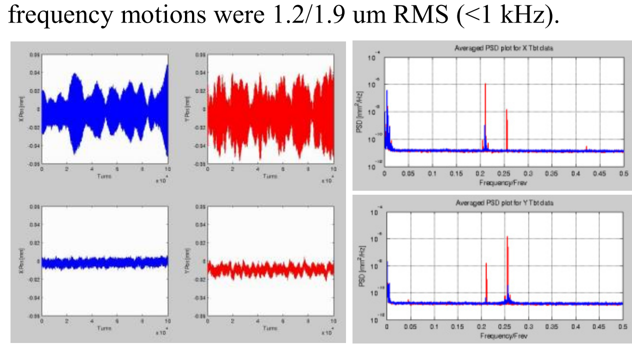

Figure 5: (left) BPM X/Y TbT data from one of the storage ring BPM C30BPM1; (right) BPM TbT data spectrum averaged from 180 BPMs, red traces were spectrum with bunch-by-bunch feedback OFF and blue trances with feedback ON.

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BUNCH CLEANING

Individual bunches can be knocked out using the integrated bunch driving functions. Highly purified single bunch will be one of the operational modes for timing related experiments. We tested the bunch cleaning using vertical bunch by bunch feedback as the vertical aperture is smaller in the ring. Due to tune dependency on bunch current and oscillation amplitude, bunch needs to be excited across the betatron tune, the sweeping range and sweeping speed was adjusted to knock out the bunch effectively. Fig. 6 shows the filling pattern after bunch cleaning. Initially there was 20 consecutive bunches filled in the ring, separate by 2ns RF period. One single bunch was able to be kicked out with little effect on nearby bunches. In the figure, the top snapshot shows bunch #9 was cleaned. Bunches were able to be knocked out in user defined patterns. For example the bottom snapshot in the figure shows bunches was kicked out every three buckets. Red arrows indicate where knocked out bunches were located.

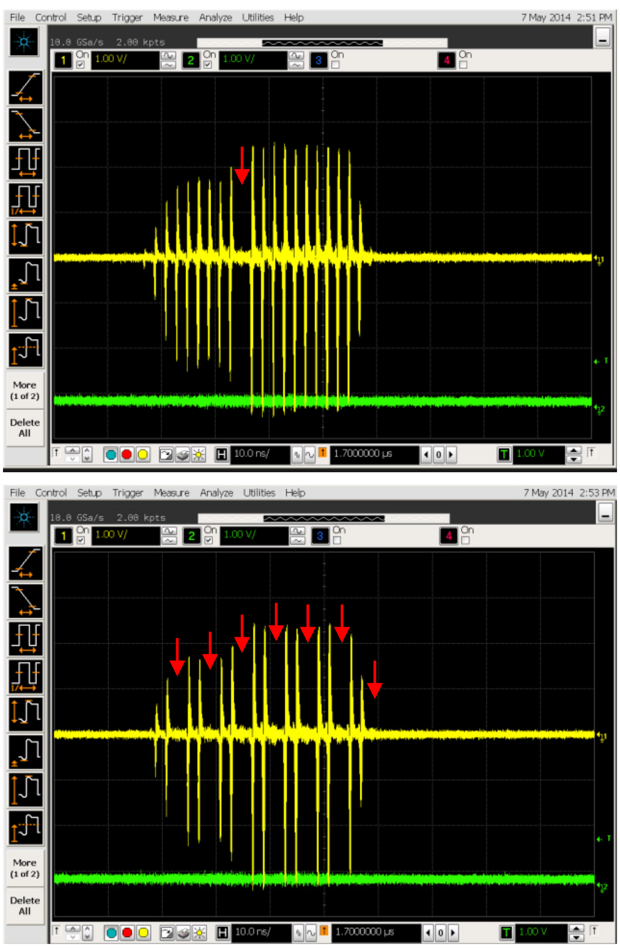

Figure 6: With an initial fill of 20 consecutive bunches, bunches at arrow locations were knocked out using vertical plane bunch excitation. (top) bunch #9 was kicked out; (bottom) bunches were kicked out every three buckets.

At this point, NSLS2 storage ring filling pattern is not well controlled. The filling pattern is mainly determined by the multi-bunch pattern from the injector. The non-uniform bunch train was placed into different RF buckets of the ring. To have an even filling pattern, overlap between injection shots may be a simply approach. Bunch cleaning function can be used to clean the unwanted bunches. Arbitrary filling pattern can be achieved by setting the proper bunch excitation mask.

Filling pattern shown in Fig 6 was using the pickup signals from button BPM. Two diagonal button signals were sent to a broadband hybrid, the SUM signal from the hybrid was feed to the 20GHz real time oscilloscope. Limited by electronics and digitizer, dynamics range of the filling pattern monitor system is typically around 10^-3. Touschek scattering in NSLS2 storage ring will be a dominant effect, the scattered electrons can be re-captured by nearby buckets. To check the bunch purity with higher dynamics ranges (six orders of magnitude or better), a new bunch purity measurement system based on single photon counting method is needed, see for example reference [6,7].

ION EFFECT

Mode analysis of acquired position data for all bunches reveals broadband beam unstable modes when the feedback was OFF. The graph in Fig. 7, compares the spectrum with and without bunch-by-bunch feedback. Beam was filled in 80% of 1320 buckets with total current of 49mA. 1024 turns' data of all 1320 buckets was used to get the spectrum. The plot shows vertical plane amplitude of the first 150 '+' or '-' unstable modes ($m\times Frev \pm f_{\beta y}$). When feedback was turned ON, most of the betatron sidebands were suppressed. With feedback OFF, several humps appeared on the broadband spectrum, which is typically ion-induced spectrum.

In multi-bunch fill, storage ring typical average vacuum pressure was around 1 nTorr. Residual gases are mainly composed of H_2, CH_4, CO and CO_2. Fig. 8 shows a typical residual gas analyzer (RGA) measured results. There are 30 RGAs installed in the ring, one per cell. In the figure was the RGA result from Cell 15 with beam stored at 10mA.

Considering a condition similar to what's shown in Fig. 6, where 80% buckets were filled, assume a total current of 50mA evenly distributed in 1040 buckets, one can calculate the ion frequencies [2,8]. With this filling pattern, the ion critical mass (see Eq. 1) is quite low. All the ions can be trapped in the electron beam potential.

$$A_{crit} = \frac{N_b r_p c T_b}{2\sigma_{x,y}\left(\sigma_x + \sigma_y\right)} = \frac{N_b r_p L_{sep}}{2\sigma_{x,y}\left(\sigma_x + \sigma_y\right)} \qquad (1)$$

Where N_b is number of particles per bunch; r_p is proton classical radius ~ 1.5×10^{-18} m; A is atomic mass of ion; T_b (or L_{sep}) is bunch separation and σ_x σ_y the RMS beam size.

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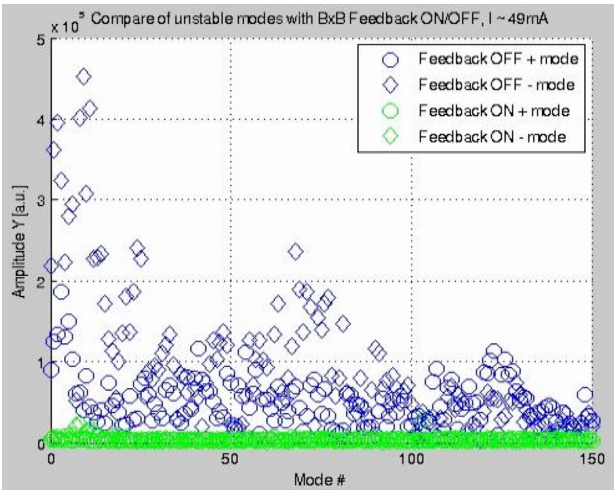

Figure 7: Comparison of vertical mode amplitude with and without bunch-by-bunch feedback.

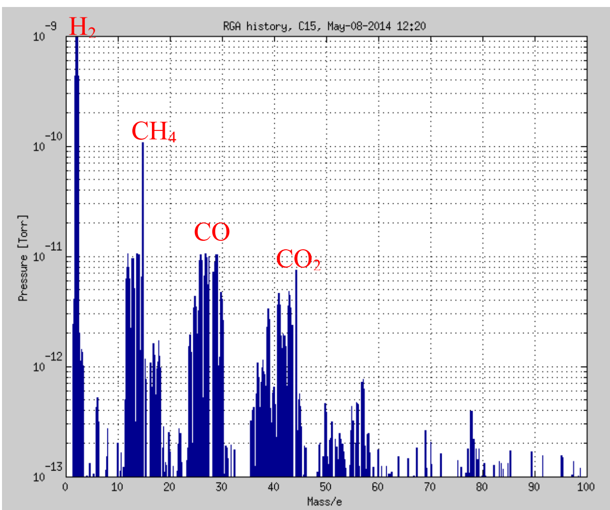

Figure 8: Typical residual gas analyzer (RGA) measured results with beam stored in the ring.

Table 1 lists the dominant ions and their oscillation frequency. Ion frequency depends on bunch current as well as beam sizes, hence it varies along the ring, as expressed in Eq. (2).

$$\omega_{ion} = 2\pi f_{ion} = \left[\frac{2 N_b r_p c}{A \sigma_{x,y} (\sigma_x + \sigma_y) T_b} \right]^{1/2} \qquad (2)$$

Table 1: NSLS2 Ions and their Effects

	H_2	CH_4	CO	CO_2
Atomic mass	2	16	28	44
Cross section [Mbarn]	0.35	2.1	2.0	2.92
Ion freq. Hor. [MHz]	13.6	4.8	3.6	2.9
Ion freq. Ver. [MHz]	47.3	16.7	12.6	10.0

What's shown in the table is averaged value in the super cell. Fig. 9 gives an example of CO+ ion frequencies in the super cell. Horizontal/vertical emittance of 2/0.01 nm.rad was used. Beam sizes were calculated from the baseline lattice without damping wigglers. From Eq. (2), ion frequency changes at different beam current. It has been observed that unstable hump moved to lower frequency when 20mA was stored in the same 80% fill pattern. Transient measurement indicated that the tail bunches in the long bunch train had larger oscillation amplitude. This is another indication of instability caused by ions.

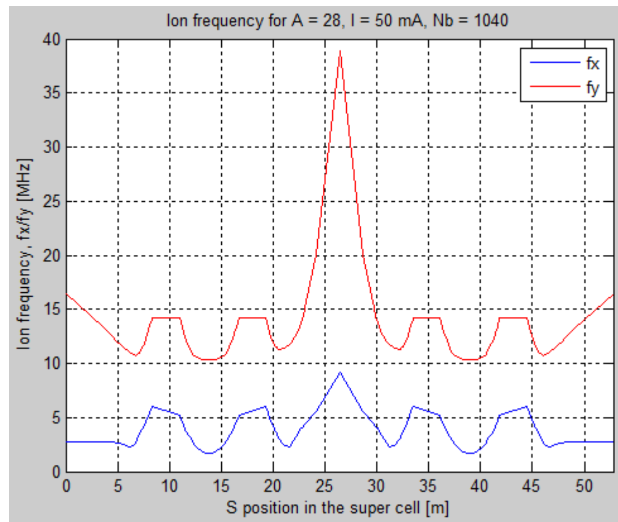

Figure 9: Ion frequency for CO^+ in one of NSLS2 storage ring super cell.

Compare the ion frequencies to the measured unstable mode in Fig. 7, it's likely that unstable modes around #125 was caused by trapped H_2 ions. Other unstable modes at lower frequency were possibly induced from heavier ions. It's worth to point out that ion frequencies calculated in Table 1 are valid for evenly distributed filling pattern, while the real machine filling pattern was not well controlled. Further studies with even filling pattern will be carried out to better understand the ion phenomena.

Besides the transverse mode analysis, with a third digitizer detecting the BPM Sum signal, one can study the longitudinal beam motion behavior. During the NSLS2 storage ring phase 1 commissioning, 7-Cell PETRA-III type normal conducting cavity was used. The cavity was full of HOMs. It was revealed from the bunch by bunch phase data that cavity HOM was making the beam unstable longitudinally. Varying the cavity temperature moved the HOM frequency.

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SUMMARY

Transverse bunch by bunch system has been designed, constructed and commissioned at NSLS2 storage ring. The system helped to suppress the coupled bunch instabilities as well as single bunch instability. Preliminary mode analysis indicate ion induced instability was observed even at 20mA stored beam (~0.02mA per bunch). Further systematic studies are necessary to better understand the ion instabilities. Besides its major role of curing instabilities, the feedback system supplies a wealth of data for diagnostics. The feedback system was tested to knock out un-wanted bunches so that arbitrary filling pattern or highly purified single bunch can be stored in the ring.

We thank the NSLS2 diagnostics group and commissioning team members for various help during installation, testing and commissioning the system.

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