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COMMISSIONING OF THE TRANSVERSE BUNCH-BY-BUNCH FEEDBACK AT SPEAR3*

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Abstract

Driven by the demand to suppress transverse beam instabilities and develop novel short pulse operation modes in the SPEAR3 storage ring, a wide-band transverse bunch-by-bunch feedback system was recently commissioned for SPEAR3. The system was demonstrated to be sufficient to suppress the transverse coupled bunch instabilities caused by trapped RF modes in one of the in vacuum insertion devices. A new function of beam instability interlock was developed and is part of the machine protection system for the in vacuum insertion devices. In addition, the bunch-by-bunch feedback system serves as an indispensable diagnostic tool that enables us to measure machine parameters, beam impedance, and characteristics of beam instability modes. In this paper, we describe commissioning and performance of the bunch-by-bunch feedback system at SPEAR3.

INTRODUCTION

SPEAR3 is a 3rd-generation storage ring with relatively low beam impedance, a benefit from the vacuum chamber design experience of the PEP II storage ring [1]. Fast ion instabilities [2] have been observed in SPEAR3 with 500 mA stored beam under degraded vacuum conditions, but can be mitigated by introducing ion cleaning gaps in the bunch train and improving the ring vacuum. Originally an iGp12 bunch-by-bunch (BxB) feedback processor with a narrow bandwidth kicker was available to damp these instabilities as well as resistive wall effects.

With the addition of the BL15 in-vacuum undulator (IVU), in SPEAR3, transverse coupled-bunch instabilities around 200 MHz were found at discrete insertion device (ID) gap settings [3]. Due to the limited bandwidth of the original kicker, these instabilities could not be suppressed by the BxB feedback system. To solve this problem, a 4-electrode wide-band kicker [4, 5] was recently borrowed from the Advanced Light Source (ALS) and installed in SPEAR3.

SYSTEM OVERVIEW

The current transverse BxB feedback system in SPEAR3 consists of 1-cm diameter BPM button pick-ups, Dimtel iGp12 feedback processors [6], two 500W RF amplifiers, and the ALS BxB kicker rotated by 45 degrees with respect to the beam axis to provide feedback in both horizontal and vertical planes. The beta function values at the BxB BPM pick-ups are $\beta_x^m = 8.3$ m and $\beta_y^m = 9.4$ m, while those at the kicker location are $\beta_x^k = 10$ m and $\beta_y^k = 2.8$ m. Even with the small vertical beta function, feedback kick is sufficient for keeping the beam stable vertically. At the same time, applications requiring large driven motion, such as bunch cleaning and resonant crabbing, demand high drive power. To address this, we recently acquired two R&K 500W RF amplifiers.

The output of each of the two R&K amplifiers is connected to one of the two strip line pairs in the kicker so that they can drive the beam using a push-pull scheme. Each Dimtel BxB processor provides two actuator output signals: one is in phase; the other is with 180^o phase shift. The in-phase signals from X and Y processors are combined and fed to the input of one amplifier, and the out-of-phase signals are summed to feed the other amplifier.

INSTABILITY CHARACTERIZATION

The BXB feedback system in SPEAR3 not only allows us to suppress the transverse beam instabilities induced by the BL15 ID but also enables us to carry out grow/damp measurements to characterize impedance that can drive beam instabilities. The grow/damp technique requires the machine to operate above the instability threshold with feedback controlling the instability. By programming the feedback loop to be open for a short period of time, one allows the transverse beam motion to grow in time. The feedback is then turned back on and the beam motion is again damped. The data for the BXB beam motion are then captured for modal analysis including the growth and damping rates of the individual coupled-bunch modes. During the BL15 measurements, in order to achieve a uniform fill pattern, the easiest case to analyse analytically, we filled all 372 RF buckets in SPEAR3 to the 500mA current limit. Under the measurement conditions ion instabilities have slow growth rates and are independent of ID gap settings. In order to create more linear optics, again for ease of analysis, the vertical chromaticity of the storage ring was decreased to 0 from its normal operating value of 2. The BL15 ID magnet gap was then scanned from the minimum value of 6.82 mm to 7.6 mm with a step size of 10 µm. Transverse high-order coupled bunch instabilities caused by the trapped RF modes in the IVU chamber are excited over certain bands of ID gap values with fast growth rates. From the grow/damp data at each gap value, the growth rates can be obtained from exponential fits the the amplitude rise time of the dominant mode at each gap setting.

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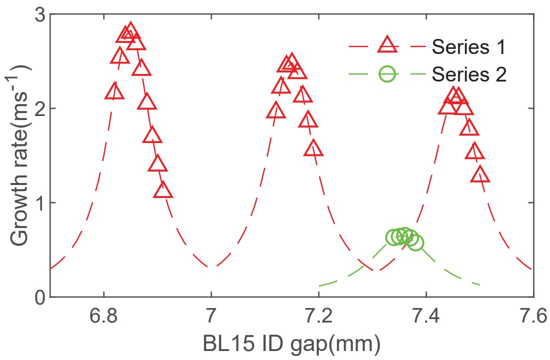

Figure 1: Growth rates of the coupled-bunch instabilities.

Within the range of the magnet gap scan of the IVU, two trapped modes were found sufficiently strong to drive instabilities. The growth rates are shown in Fig. 1, along with a numerical fit to the data points. Although the measurements were made with slightly different stored beam currents at each data point, we scaled all results to values corresponding to a stored beam current of 500 mA. Since the cut-off frequency of a ridge waveguide increases with the gap height, when increasing the gap of the IVU, the frequency of the trapped mode will change continuously. In our case the change is sufficiently large that the trapped resonant RF modes can cross the lower betatron side-bands of several adjacent revolution harmonics. With about a 0.8 mm change of gap, the stronger resonance, shown as series 1 in Fig. 1, travels through three coupled bunch instability modes: mode 156 through 158. The circle markers represent measured data for mode 118, which is driven by another, weaker, ridge waveguide resonance. By fitting the measured data Fig. 1, to Lorentzian functions (dashed lines), we can derive the gap values at the peaks and the quality factor of each resonance mode. Table 1 lists the results of the calculations.

Table 1: Mode Properties

Gap(mm)	Mode ID	Freq. (MHz)	Q
6.85	156	199.51	456
7.15	157	200.86	444
7.45	158	202.12	446
7.36	118	150.84	237

INSTABILITY INTERLOCK

SPEAR3 has a 7.6 m straight section that accommodates two IVUs, BL12-1 ID and BL12-2 ID. It is important to prevent the upstream undulator radiation from damaging the downstream ID. Besides tightening the orbit interlock limit at BL12-1 ID and adding a radiation mask at the entrance of BL12-2 ID, a beam instability interlock was also developed using an iGp12 BxB feedback processor. The interlock system detects vertical orbit oscillation amplitudes and, when necessary, creates a GPIO output trigger to trip the RF system resulting in a fast beam dump.

The interlock control panel is shown in Fig. 2. Three parameters, saturation time, timeout time, and trip threshold, are adjustable to define the trip condition. The interlock

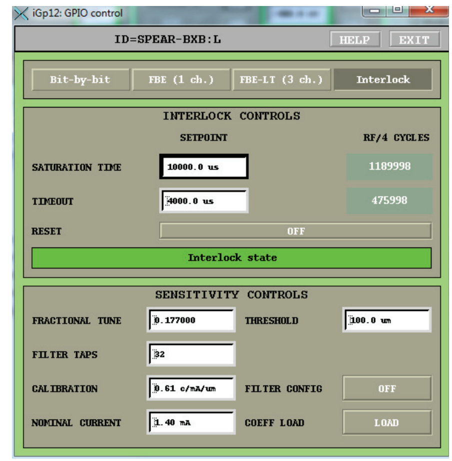

Figure 2: Instability interlock control panel.

monitors the turn-by-turn vertical oscillation data at fixed BPM position. When the orbit oscillation amplitude first exceeds the trip threshold, instead of an immediate trip, the interlock will start the saturation timer. In SPEAR3, the typical settings for the trip threshold is 100 μm and for the saturation timer is 10 ms. A second timer (timeout timer) is activated when the beam oscillation drops below the threshold. This timer is normally set to 4 ms in SPEAR3. Every time the oscillation amplitudes exceed the threshold this timer is restarted. If the saturation timer elapses, interlock will trip. If, on the other hand, the timeout timer reaches zero, the saturation timer is cleared. This scheme allows the system to ignore short bursts of oscillation due to injection, but to activate the interlock in cases of sustained motion.

Currently, the instability interlock is a reliable operating part of the machine protection system in SPEAR3.

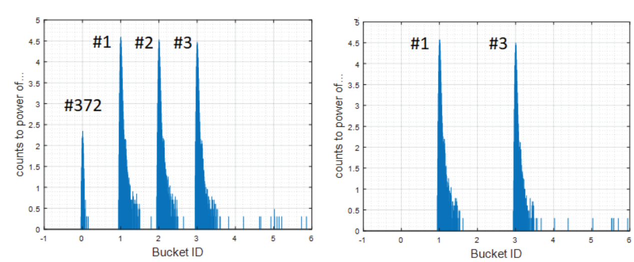

Figure 3: Filling pattern before (left) and after (right) bunch cleaning.

BUNCH CLEANING

Some timing-related user experiments require high bunch purity in SPEAR3. Occasionally, the stored beam had to be dumped due to spilled charge into satellite buckets near the timing bunch during the user operation. Therefore, we conducted studies of bunch cleaning in SPEAR3. The iGp12

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BxB feedback processor has a built in function for bunch cleaning by kicking individual bunches out of the ring. The cleaning normally takes place in the vertical plane due to the small vertical aperture. However, after testing, we found out that, due to the relative large vertical aperture, lower kicker shunt impedance and small vertical beta function at the kicker, we could not conduct bunch cleaning in the vertical plane. An alternative approach was explored by driving the unwanted bunches horizontally into the septum using the BxB system during injection period when the stored beam is normally deflected toward the septum.

During the experiment, we filled 3 adjacent buckets with a total of 5 mA, approximately the same charge as for user operations. With a PicoHarp 300 single photon counting system, the bunch purity was measured to high precision at a diagnostic beam line. As shown in Fig. 3, before the bunch cleaning, spilled charge filled in the unwanted bucket #372 preceding the first bucket, is about 1% of the charge in the filled bucket. We then turned on the injection kickers to create the matched injection bump for stored beam without a beam injection and successfully eliminated the charge from bucket #372 while keeping the filled charge in bucket #1. The resulting bunch purity is better than 1:10000. Next, we conducted the same experiment with user operation conditions including 500mA stored beam and top off injection every 5 minutes. Again, the spilled charge is well controlled by the bunch cleaning, however, we had trouble in completely cleaning a fully filled bucket. The reason is due to the injection scheme of SPEAR3: during each injection cycle only one bunch is filled and the injection kicker pulse advances with the target bucket. Therefore, the bunch we want to clean is not always experiencing the maximum kick from the injection kicker. Nonetheless, the horizontal bunch cleaning scheme provides us the on-demand capability to provide high bunch purity during user operations. Currently we are investigating options to conduct vertical bunch cleaning by acquiring BxB feedback kickers with higher shunt impedance combined with vertical scrapers.

DUAL-PLL TUNE MEASUREMENT

The transverse kick factor can be calculated from the coherent tune shifts between two bunches with different charges. With jitter of betatron tunes the main challenge to conduct high precision measurements. The iGp12 feedback processors in SPEAR3 have a built-in feature that can track the betatron tune of a single bunch with a phase lock loop (PLL) by driving the bunch with a local RF oscillator. In order to conduct the impedance measurement, we need the capability to track the tunes of two bunches simultaneously so that the common mode variation of tunes can be subtracted. Currently, we are in the process of developing such function. The preliminary proof-of-principle experiment shows that this technique is very promising. During the experiment, we reassigned the functions of different feedback processors so that in the vertical plane we can create two PLLs to track two different bunches. The two bunches were filled with different charge and separated by about half of the ring circumference for tune tracking studies. The results showed good consistency and low noise in the data. In

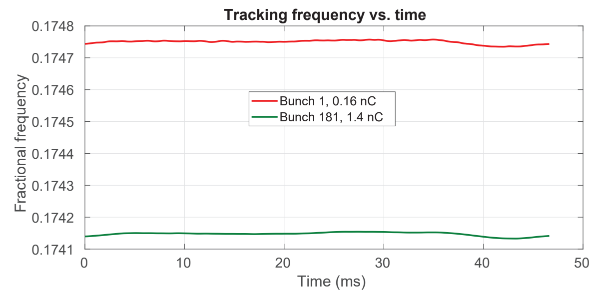

Figure 4: Tune tracking of two bunches with different charges in SPEAR3.

Fig. 4, we show an example of tune tracking studies with two bunches filled with Q_{181}=1.4 nC and Q_1=0.16 nC, respectively. The tunes were measured at a BPM with β_y=9.4 m, where the vertical tunes of bunch #1 and bunch #181 are: ν_1=0.1747±9.2x10^{-6} and ν_{181}=0.1741±9.2x10^{-6}. The difference is $\delta\nu$=0.0006±1.7x10^{-6}. The error bars were calculated from the standard deviation of the data over the tracking period of 50 ms. The improvement in the uncertainty of $\delta\nu$ from the single bunch tune, by a factor of 5.4, is due to the rejection to the common mode betatron tune wandering. Furthermore, using the following formula:

$$k_\perp = \frac{4\pi E/e}{\beta_y(Q_{181} - Q_1)}(\nu_1 - \nu_{181}), \quad (1)$$

where E and e represent beam energy and single electron charge, respecteive, we can calclate the kick factor: $k_\perp$=1941±5.4 $V/(pC \cdot m)$.

MATLAB GUI TOOLS

The EPICS EDM tools and MATLAB tool box with the BxB feedback processors provide complete functionality for system tuning and data acquisition, but they can be overwhelming for non-expert users. To allow the SPEAR3 operators to conduct routine checks the system performance, we developed a MATLAB GUI tool, BxBtuning, to characterize system performance by measuring the calibration factor and scanning the timing parameters. Another dedicated MATLAB based GUI tool [7] has also been developed for physicists to acquire data and conduct grow-damp measurements from one interface.

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