MACHINE STUDIES WITH LIBERA INSTRUMENTS AT THE SLAC SPEAR3 ACCELERATORS

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Abstract

Turn-by-turn BPM readout electronics were tested on the SPEAR3 booster synchrotron and storage ring to identify possible improvements for the booster injection process and to characterize processor performance in the main storage ring. For this purpose, Libera Spark [1] and Libera Brilliance+ [2] instruments were customized for the booster (358.4 MHz) and SPEAR3 storage ring (476.3 MHz) radio-frequencies, respectively, and tested during machine studies. Even at low single-bunch booster beam current, the dynamic range of the Libera Spark readout electronics provided excellent transverse position resolution during the linac-to-booster injection process, the energy ramp phase and during beam extraction. Booster injection efficiency was analyzed as a function of linac S-band bunch train arrival time. In the SPEAR3 storage ring, turn-by-turn Libera Brilliance+ measurement capability was evaluated for single and multi-bunch fill patterns as a function of beam current. The single-turn measurement resolution was found to be better than 15 microns for a single 1.5 mA bunch. The horizontal single-bunch damping time was then observed with the 238 MHz bunch-by-bunch feedback system ON and OFF, and the multibunch fill pattern stability evaluated as a function of total beam current.

BOOSTER BPM MEASUREMENTS

The booster synchrotron features a 10 Hz resonant-driven White circuit with a 100 MeV to 3 GeV energy ramp in ~37 ms. Of significance, injection into the booster consists of about 7 S-band bunches selected from a 1 µs S-band bunch train produced in a thermionic RF electron gun. The S-band bunches are not phase-locked to the booster and the arrival time can vary due to thermal and electronic drift over time.
The Libera Spark was configured for highest sensitivity and was able to accurately measure single bunch position during the 37 ms booster ramp phase.

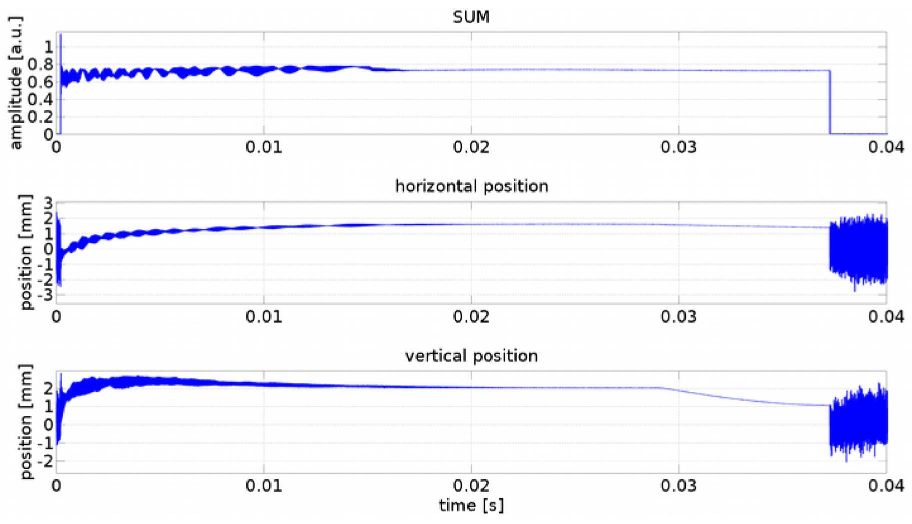

Figure 1: Single acceleration cycle in the SPEAR3 booster ring.

Figure 1 shows the beam position and charge (SUM) throughput the full booster acceleration cycle. At each injection cycle about 7 S-band bunches are injected from the linac into a single booster RF bucket. The S-band bunches are separated by 250 ps and radiation-damp into a single booster bunch during the energy ramp. By 17 ms the radiation damping process is complete and modulations are not evident anymore.

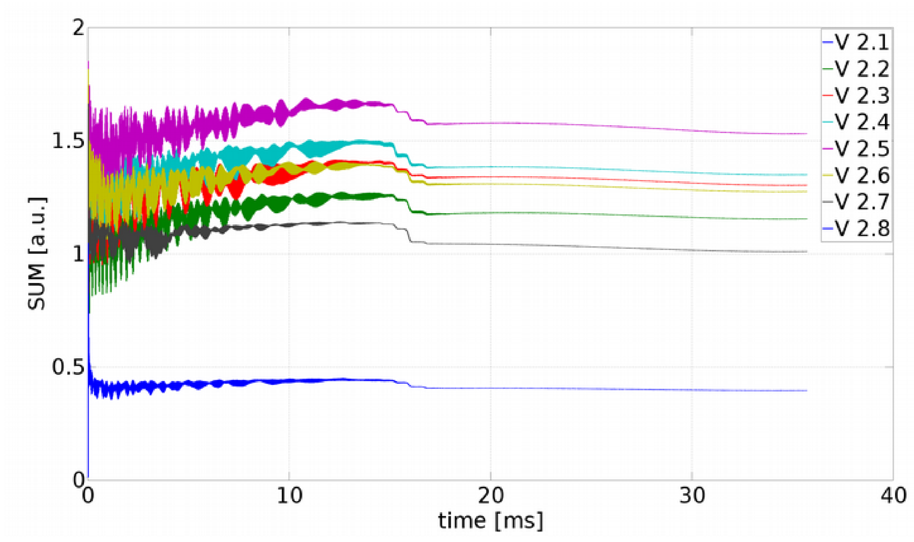

Figure 2: Single acceleration cycle in the SPEAR3 booster ring.

The overall charge capture efficiency depends on the S-band bunch train arrival time. We manually varied the arrival time and monitored the injection dynamics with the Libera Spark. The nominal arrival time setpoint was 2.5 V where each 0.1 V corresponds to a delay of 40 ps. Figure 2 shows the SUM (charge) for series of different S-band bunch train arrival times. The injection efficiency went down by over 50% for a setpoint of 2.8 V (-120 ps delay).

To test the Brilliance+ module in a 'dynamic' beam motion environment, we pulsed a single horizontal injection kicker to instantaneously ping the beam in the horizontal plane. Tests were performed with the 235 MHz bunch-by-bunch (BxB) feedback system OFF and ON and the Brilliance+ module triggered synchronously with the 10 Hz injection kicker. Results are shown in Figure 5 and Figure 6.

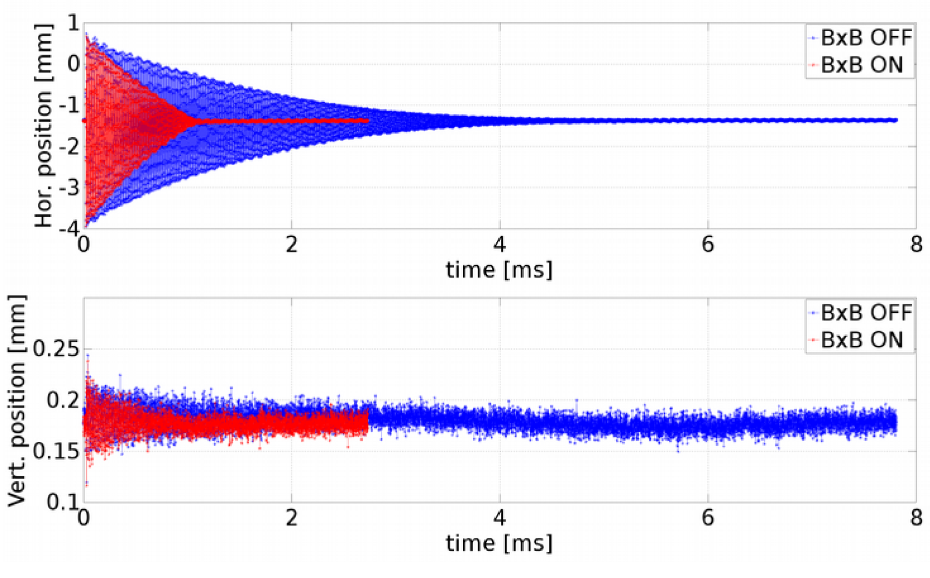

Figure 5: The horizontal betatron oscillations damp with the characteristic few msec exponential damping time for the SPEAR3 magnet lattice (BxB OFF, blue line). The 'scalloping' pattern seen on the beam envelop is again due to synchrotron oscillations. When the BxB feedback is switched ON, the betatron oscillations decay in about 1 ms (1,300 turns).
The lower plot shows coupling into the vertical plane is relatively small.

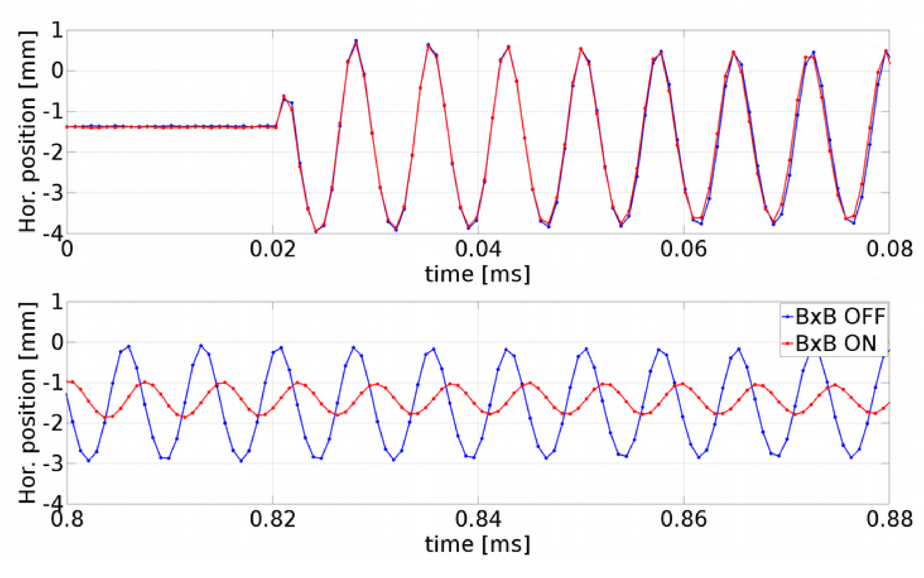

Figure 6: The top plot shows data for the first 75 turns where the effect of feedback is still relatively small. The bottom plot starts at 800 µsec and shows 100 turns after the initial injection kicker event. In this case we see both the damping action of the BxB feedback system and a phase shift due to an effective change the reactive impedance seen by the beam with the feedback loop closed.

SPEAR3 BPM MEASUREMENTS

SPEAR3 is a 3 rd generation, 3 GeV synchrotron light source with 234 m circumference. The storage ring nominally operates with 500 mA circulating beam current and approximately 1.8 mA/bunch (1.4nC). Topup occurs every 5 minutes using about 50 pulses of single-bunch charge at a 10 Hz rate. Libera BPM processor electronics were installed in the booster ring and in the SPEAR3 storage ring to study measurement performance under different beam conditions.
To evaluate the potential for a hardware upgrade, turn-by-turn beam measurements were made with a Libera Brilliance+ processor demonstrating accurate, single-bunch, single-pass measurements down to a bunch current of about 250 µA (200 pC charge).

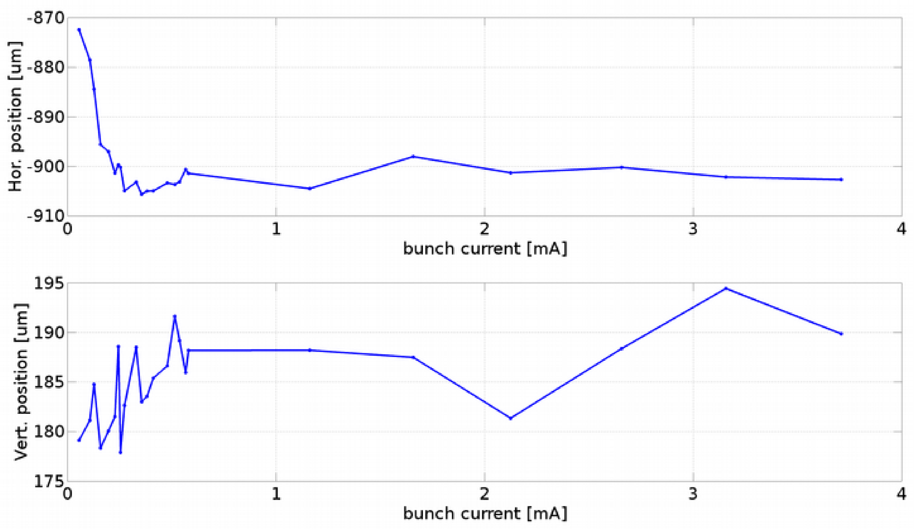

Figure 3: Single bunch, single turn measurement capability as a function of electron beam current. Gain and phase compensation were not enabled hence the large deviation between 2 and 3 mA.

As seen in Figure 3, above low-charge single bunch values of 30-50 nA, the beam position measurements stabilized to approximately 10 µm peak-to-peak between 0.2 mA to 3.7 mA. After 2 mA, the automatic gain control in Brilliance+ increased channel attenuation two times. Since the gain compensation circuit was not activated, a position deviation is observed in the vertical direction between 2 and 3 mA.

Turn-by-turn noise performance was then evaluated for single bunch currents ranging from 0.5 mA to 5 mA. For these measurements, the Kx and Ky scaling coefficients were set to 15 mm (default 10 mm). Excerpt from results are listed in Table 1 and indicate the RMS noise figures are satisfactory providing reliable readout of the electron beam orbit position in single bunch mode.

Table 1: Single bunch, turn-by-turn noise performance in a bandwidth of 0-0.6 MHz. Kx and Ky scale coefficients were set to 15 mm.

Beam current	Horizontal plane (RMS)	Horizontal plane (RMS)
1 mA	20 µm	19 µm
2 mA	14 µm	12 µm
3 mA	10 µm	8 µm
4 mA	10 µm	8 µm
5 mA	9 µm	7 µm

Since the BPM buttons are located in a region of non-zero dispersion, significant contributions from ~11 kHz synchrotron oscillations were found above1.5 mA bunch current and add between 3-5 µm systematic RMS noise. Using the same single-bunch data from Table 1, the FFT algorithm was applied to the raw turn-by-turn data and is shown in Figure 4.

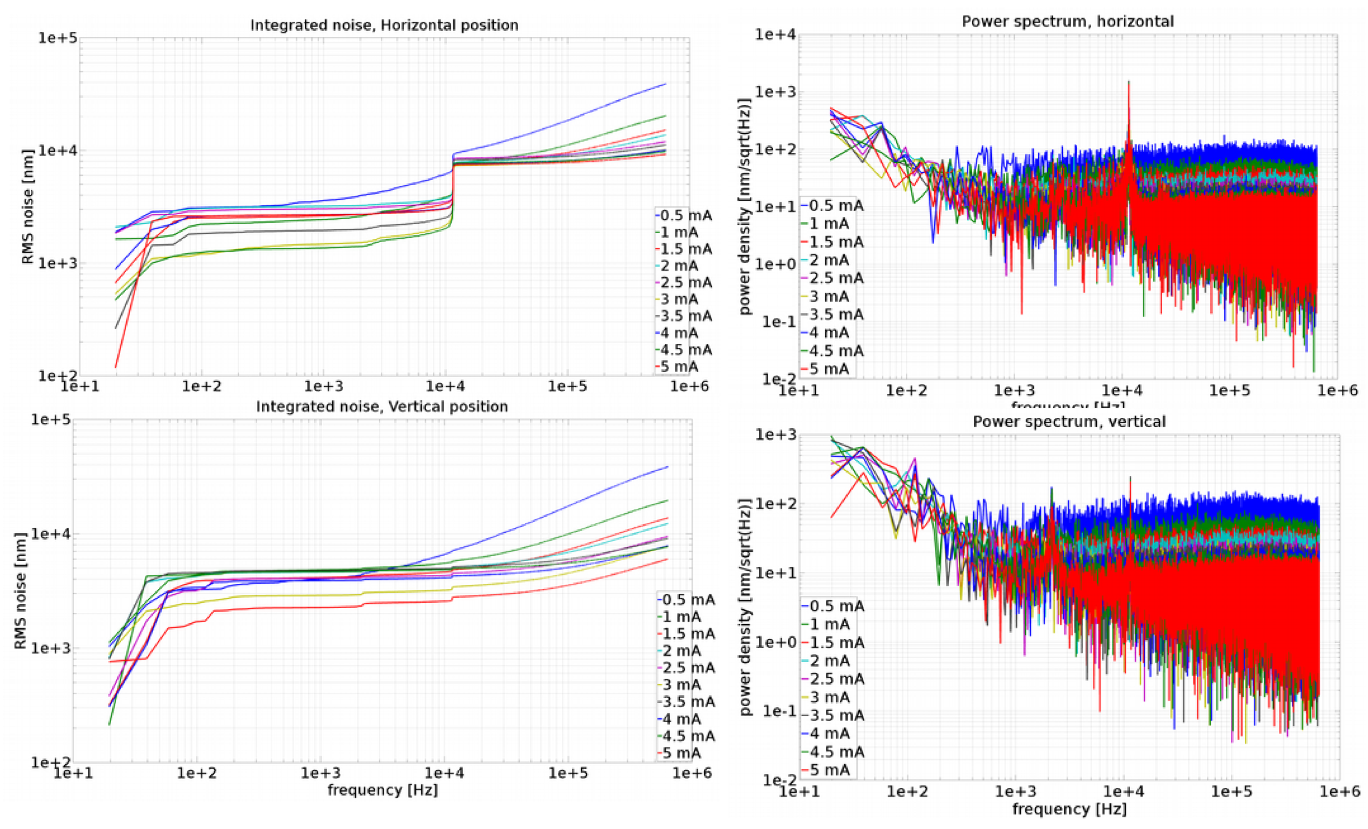

Figure 4: Integrated noise over a ~650 kHz bandwidth (left plots) and power spectrum (right plots). Above the low 500 µA current level, the step seen at the synchrotron frequency is approximately equal for all bunch charges.

Conclusion

In this paper we report preliminary tests of Libera Spark and Libera Brilliance+ BPM processors operating on the SPEAR3 booster and main ring, respectively. At the booster the Spark processor provides more accurate transverse beam position data with much better time resolution than previously available. An important effect involving vertical beam orbit shift induced by the pulsed extraction septum at the top of the energy ramp was discovered.
The Libera Brilliance+ processor in SPEAR3 also provided accurate turn-by-turn beam position measurements over a wide range of single-bunch and multi-bunch operating conditions. Since the physical BPM buttons were located at a region of horizontal dispersion, an FFT of the data clearly indicated the presence of synchrotron oscillations. Of interest the Brilliance+ turn-by-turn data provides an accurate beam diagnostic tool for dynamic BxB feedback events including the ability to resolve phase shift in the oscillation data. In the near future SSRL will install a Libera Spark processor on the Booster and is in the process of testing a Spark processor on the SPEAR3 ring to upgrade turn-by-turn diagnostics capabilities.

Acknowledgement

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References

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