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COMMISSIONING OF THE LIBERA BEAM LOSS MONITORING SYSTEM AT SPEAR3*

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Abstract

SPEAR3 is a third generation synchrotron radiation light source, which operates approximately 9 months each year with a very high reliability. The beam loss monitoring system in the storage ring has recently been upgraded to the modern Libera system from the original legacy hardware. During the initial stage of the new beam loss monitoring system deployment, it proved to be useful for a new lower emittance lattice commissioning in SPEAR3. In this paper, we will report progress in the Libera system commissioning in SPEAR3 and present some first results.

INTRODUCTION

In a high brightness synchrotron radiation light source, it is of great importance to monitor and reduce electron beam losses to improve machine performance and machine protection. As a result, besides various radiation detectors, many facilities also equip with a dedicated beam loss monitoring system to characterize the beam losses. The beam loss monitoring system in SPEAR3 was first deployed to conduct a precise measurement of electron beam energy in the storage ring by observing the resonant spin depolarisation of the beam [1]. The beam loss detector (BLD) was a NaI scintillator coupled to a photo-multiplier tube (PMT). The loss events captured by the scintillator were converted to analog signals and counted by a Struck 3820 scaler, which was integrated into the EPCIS control system and provided pulse counts as the loss rate. NaI detectors also proved to be beneficial for other accelerator physics experiments [2]. However, there were several drawbacks to the system. First, only one high voltage power supply (HVPS) delivered voltage to each PMT, which was not ideal because each detector could require different bias voltage for optimal performance. In addition, the data acquisition system relied on legacy NIM hardware for signal processing. They were not reliable and hard to maintain. As a result, we were motivated to upgrade the SPEAR3 BLM with modern technology. Inspired by successful experience from ESRF [3, 4] and SOLEI [5], we chose the commercial solution of Libera BLM system from Instrumentation Technologies [6].

HARDWARE DEPLOYMENT

The Libera beam loss monitoring solution consists of two main components, the BLD and the beam loss monitor (BLM). Similar to the original BLD in SPEAR3, the Libera BLD is a PMT-based detector with a plastic scintillator, EJ-200 [7]. The PMT is from Hamamatsu with a built-in HVPS module. As shown in Fig. 1, the scintillator and the PMT are housed in a compact aluminium enclosure with a lead sleeve to shield the X-rays from the synchrotron radiation during operation. The typical response from the PMT for a loss event of the cosmic background detecting in the lab is also show in Fig. 1 to illustrate the pulse response of the detector. The PMT output signal from the detector has several ns rising time and about 20 ns falling time. The

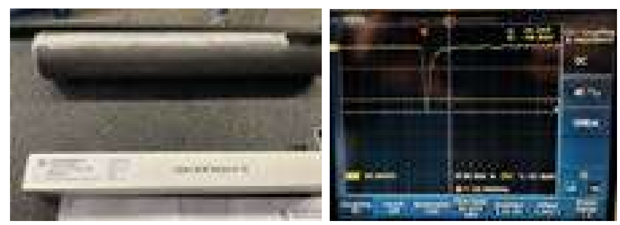

Figure 1: Libera BLD with the lead sleeve (left) and the analog signal for background cosmic ray detection (right).

Libera BLD essentially is a photo multiplier tube (PMT) with a built-in scintillator to convert an individual loss event to a fast analog pulse lasting for about 20 ns. On the other hand, the Libera BLM, each of which can support 4 BLDs, is the digital processing unit for the analog signals from loss events. The ADC of the BLM samples this analog signal at a sampling rate up to 125 MHz or a sampling period of 8 ns. As a result, an isolated beam loss event is converted to a digital peak being formed by about 3 sampling points. The bucket spacing of SPEAR3 is 2.1 ns, therefore, the Libera system is not able to resolve the beam loss with bunch-by-bunch resolution. However, this is still an improvement from the old system, which had a resolution of about 400 ns. Another benefit from the new system compared with the old one is power delivery and gain control from the BLM unit to the BLDs. In SPEAR3, the Libera BLM was integrated into the EPICS control system for easy configuration and control [8].

3 BLMs with 12 BLDs were acquired from the vendor with 9 BLDs installed in SPEAR3. These BLDs are distributed around the storage ring: 1 at the movable scrapers; 1 at a designated Touschek loss point at the center quadrupole at Girder 3 (3G QFC); 1 at the injection septum magnet; 1 at each of the four in vacuum undulators (IVUs); 1 at each of the two elliptical polarized undulators (EPUs). As shown in Fig. 2, the location for the BLD installation in SPEAR3 is limited due to the dense layout of the accelerator components. Most BLDs were installed horizontally in the beam plane so that the scintillator was close to the ring chamber

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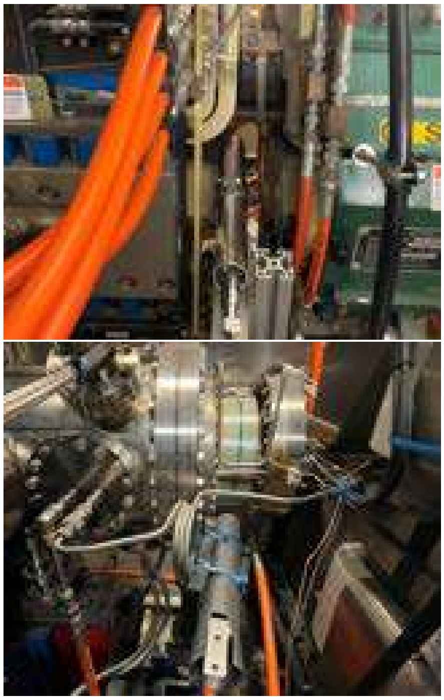

Figure 2: The Libera BLD installed at the 3G QFC (top) and at the ID 12-2 (bottom), one of the SPEAR3 IVUs.

and the electronics in the PMT could have enough distance from the adjacent magnet poles to avoid the interference from the magnetic fringe fields. Nonetheless, it was aware that the installation of the BLDs may not be ideal for beam loss detection especially for comparing the loss events at different locations. Due to limited resources, the BLDs have not yet been calibrated.

BEAM MEASUREMENT

Counting Mode

The BLM software provides two digital processing options for users to choose: triggered data buffers and counter streams. For the triggered data buffers, the sampled input beam loss signals are summed or averaged and stored to the SUM and AVG buffers. In this approach, a phase locked loop (PLL) with input from the ring clock controls the sampling frequency so that the buffered data correlates with the turn-by-turn beam loss. For the counter streams, the ADC data is continuously processed for pulse counting to provide the count rates for the beam loss measurement. This counting mode is particular of our interest because it offers the same function as the old system in SPEAR3. Therefore, we have been focusing on the implementation of the counting mode. Next, we are planning to develop functions to take advantage of the triggered data buffers because they can detect fast beam loss during beam injection or when shutting down the RF.

ADC Protection

The Libera BLM conditions the raw PMT signal from the BLD though a input termination (50 Ω or 1 MΩ), and a programmable attenuation before digitizing the signal with a 14bit ADC. This allows individual sensitivity control for each channel and each BLD. However, during operation, when the injection occurs, the loss events increase significantly and the ADC can be saturated by the input signal. We were particularly concerned about the ADC damage over a long period time in saturation, therefore, before keeping the BLM on line during operation, we developed an auto configuration program to switch the BLM configuration right before each injection. The program monitors an EPICS PV changing status 2 seconds before the start of the injection process to switch the BLM to a preset configuration designated for the injection period. Figure 3 shows an example of the program working during 5 injections. The blue curve represents the maximum ADC count provided by the BLM software. The ADC saturation level is 8191 and would occur during the injection if keeping the BLD configuration unchanged. For this detector, the gain control voltage (red line) was reduced from 0.7 V for measuring the lifetime loss between top off injection to 0.5 V during the injection, which was effective in avoiding the ADC saturation.

Figure 3: The gain of the BLD was switched from 0.7 V to 0.5 V at injection to avoid ADC saturation.

Lifetime Loss Measurement

To confirm that the loss rates measured in the counting mode represent beam lifetime loss, we conducted beam loss measurements by moving the horizontal scraper to fix the loss point of the ring. During the experiment, 100 mA beam was filled in the ring. As mentioned earlier, the vacuum chamber for the 3G QFC has a reduced horizontal aperture and the location was designed with high nonlinear dispersion bump to capture most of the lifetime loss during operation. As a result, when the horizontal scraper was parked far away from the beam, as shown in Fig. 4, the loss rates were largest at 3G QFC, about 2000 counts/sec. The next two most lossy points are the ID5, at about 500 counts/sec, and the septum, at about 60 counts/sec. This was mostly as expected except that the reading from ID5 was a bit higher than expected.

As shown in Fig. 5, when closing the scraper gradually, the dominated loss point started to shift away from the 3G QFC to the scraper. The scraper position was at -6mm when the loss rates at the two locations were same. We stopped the scraper at −2.6 mm.

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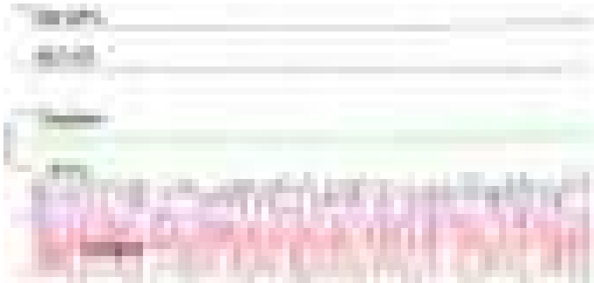

Figure 4: The loss rates in counts/second for different BLDs (in logarithmic scale) with the scrapers were parked.

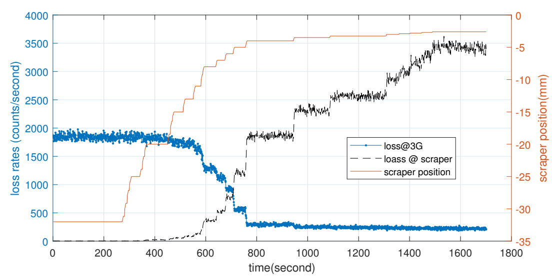

Figure 5: The loss rates in counts/second for different BLDs (logarithmic scale) when the horizontal scraper was scanned.

The Touschek lifetime is determined by the beam current and the 3D beam size. By adjusting the skew quadrupoles, we changed the vertical beam size slightly which in turn changed the lifetime. The loss rates can also be calculated from the time derivative of the stored beam currents (NPCT loss rates). We compared the measured results from the two different methods with the horizontal scraper was parked and closed to −2.6 mm respectively. The results are shown in Fig. 6. When the scraper was parked, the loss rate at 3G QFC was compared with the NPCT loss rate scaled by a factor of 50,000; when the scraper was moved to −2.6 mm, the loss rate at the scraper was used for comparison with the NPCT loss rates scaled by a factor of 25,000. In both cases, the measured loss rates from the two methods agreed well confirming accurate determination of beam lifetime measurements with the BLM system.

Injection Loss

During normal operations, we were able to capture the raw ADC signals in the data buffer of the BLM during beam injection and between the fills. We compared them in Fig. 7. Due to the large amount of loss events during the injection, the PMT signals piled up resulting in long pulses lasting more than 1 turn. Therefore, pulse counting is not useful to characterize the injection loss. On the other hand, for lifetime loss between the fills, the loss events were more isolated leading to the clean impulse response signal of the PMT. This is the reason that the counting mode works well for characterize the lifetime loss. In addition, the signals for injection was more repeatable, but the lifetime loss signal was not due to its stochastic nature.

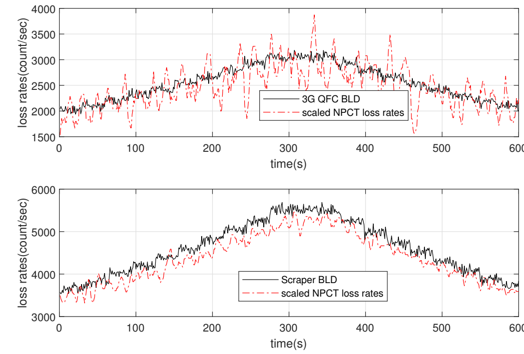

Figure 6: Comparison of the loss rates measured from the BLDs and the current monitor in the storage ring when the scraper was parked (top) and closed (bottom).

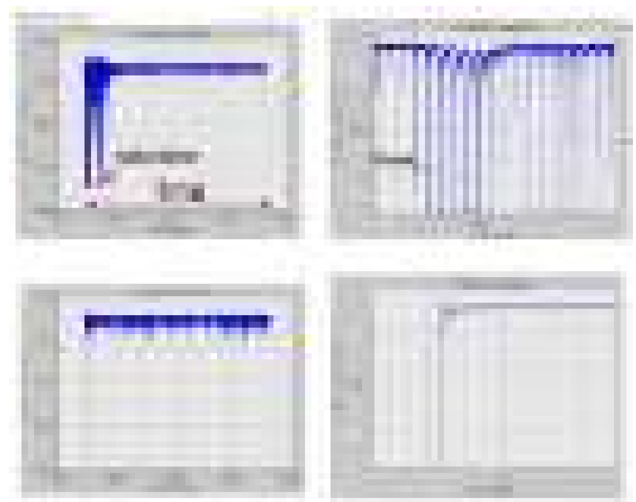

Figure 7: Raw ADC signals of the 3G-BLD for the injection beam loss (top left:the injection loss signal for 1 ms; top right: zoomed in) and the life time beam loss (bottom left: lifetime loss signal for 1 ms; bottom right: zoomed in).

3G DUMP APERTURE CHARACTERIZATION

The Libera BLD was helpful to characterize the designated 3G QFC chamber aperture when the new lower emittance lattice was commissioned in 2021 [9]. Based on the tracking simulations, the operation of the new lattice with reduced emittance of 7 nm required the modification of the 3G QFC chamber half aperture from −32 mm to −15 mm. Otherwise, the lifetime loss would mostly occur at the septum, and the RF beam dump loss would distribute at different insertion devices depending on the magnet gap settings of the in vacuum insertion devices. A new insert was designed and installed in the 3G QFC chamber to reduce the aperture to −15 mm and serve the designated beam dump (3G dump) when shutting off the RF. During beam commissioning of the new lattice, it was critical to confirm the 3G QFC chamber aperture was indeed at or smaller than −15 mm. The normal beam based technique to probe the aperture is to

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create local orbit bump till the beam gets lost at the aperture. However, due to the large aperture, the steering magnets are not strong enough to move the beam to the aperture. Alternatively, we conducted beam based aperture scan with both the injection kicker and the steering magnets. The 3G dump aperture was then determined using tracking simulations based on the beam based measurement results. This indirect characterization was later confirmed by the RF beam loss measurement with the libera BLD at 3G QFC.

As described earlier, in the 7 nm lattice, when cutting off the storage ring RF power abruptly, according to the tracking studies, the beam loss will be captured mostly at the 3G dump if its physical aperture in the -x direction is less than 15 mm. However, if a local orbit bump is applied to the beam orbit at the 3G dump in the +x direction, away from the dump, at some point, the RF dump loss can distribute to other locations. This process was simulated in tracking studies by changing the 3G dump aperture. With BLDs installed at the 3G dump and the septum, we were able to perform RF beam dump studies and compare with the tracking results. During the experiment, we filled a single bunch of 4 mA in the 7 nm lattice. The RF was turned off abruptly with different DC bumps at the 3G dump, while the BLDs near the 3G dump and the septum were triggered to acquire the raw ADC data. The measurement data for the BLDs are compared in Fig. 8.

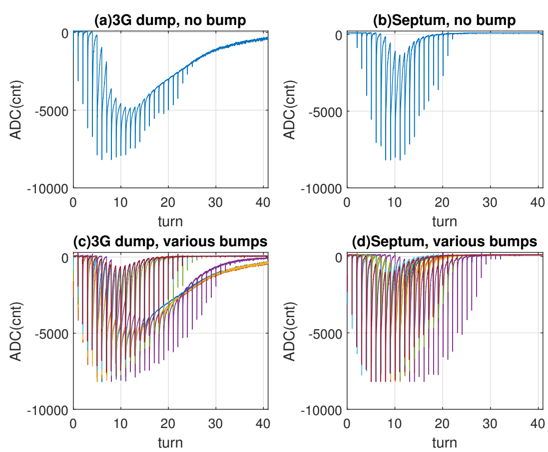

Figure 8: Raw ADC signals of the BLDs at 3G dump and Septum for the RF beam dump measurements.

Due to the large number of electrons lost when cutting off the RF, loss signals pile up and form broader peaks lasting nearly one turn as shown in Fig. 8. These broader peaks were seen in the BLD signals from the 3G dump and the septum. The lower envelope of the signals at the 3G dump appear to have larger amplitude and last longer when comparing the signal profiles in Fig. 8(a) and (b). This can suggest that the 3G dump has much higher loss event rates resulting in more significant signal pile-up. Another observation from the BLD signals is that the beam appears to be gone completely within 30 turns after the RF is cut off. The results with different orbit bumps away from the 3G dump are shown in Fig. 8(c) and (d). They correspond to beam bumps of 0 mm, 1.5 mm, 2 mm, 2.5 mm, 3 mm, 3.5 mm, and 4 mm, respectively, at the 3G dump. The signal profiles at the 3G dump change little when the beam bump is smaller than 3 mm (green line).When the DC bump is larger than 3 mm, the BLD signals have a reduced lower envelope and look similar to the signals from the septum BLD. We believe the integrals of the BLD signals in these measurements have strong correlations to the local beam loss rates, therefore we plot the results in Fig. 9 along with the tracking simulation results with different 3G dump apertures. If we correlate the turning points in the two plots, we conclude that the 3G dump aperture is about −14.25 mm, which agrees well with the result of −14.5 mm from the aperture scan. The measured 3G dump aperture was slightly smaller than the design value of −15 mm, but still met the operational requirements.

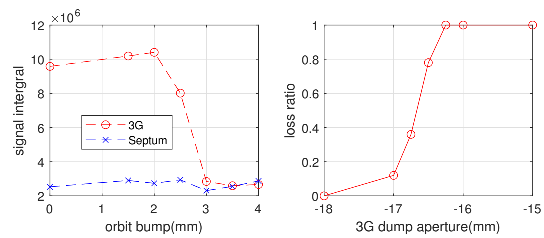

Figure 9: BLD measurments vs tracking simulations.

SUMMARY

The commissioning of the Libera beam loss monitoring system at SPEAR3 is still in progress, but early results are promising and interesting. Next, we will focus on developing the functionality to characterize injection loss around the storage ring.

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