

OBSERVATION OF BEAM LOSS SIGNAL AT THE SPS STORAGE RING

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Abstract

Beam Loss Monitoring (BLM) system is an essential tool for observing beam instabilities and hence for machine protection. At the Siam Photon Source (SPS) storage ring, the BLM system is used to check the beam behavior due to optics perturbation, ion trapping, and vacuum leakage. A network of 50 PIN-diode detectors from Bergoz has been installed around the ring at the positions of high particle density. These positions are at the values of large betatron and dispersion functions in the machine lattice. The operational results of tune scanning verses loss rate in the resonance diagram are described. These results will be useful for improving the beam performance in terms of lifetime and beam stability.

INTRODUCTION

Siam Photon Source (SPS) is a synchrotron light source composed of two 20 MeV linacs, a 1.0 GeV Booster Synchrotron (SYN), and a 1.2 GeV electron storage ring. The SPS storage ring contains four Double Bend Achromat (DBA) super periods with four straight sections. Each symmetric period consists of four focusing quadrupole magnets (QF), three defocusing quadrupole magnets (QD), and two bending magnets (BM). The electron beam is filled twice a day to 150 mA. Three insertion devices; Undulator (U60), Superconducting Wavelength Shifter (SWLS), and Multipole Wiggler (MPW), have been installed and commissioned at three of the straight sections [1]. It was observed that loss rate at the SPS storage ring increased due to the insertion devices operation. A BLM system has been used to investigate the beam loss behavior, which can be a result of optics perturbation, vacuum leakage, and ion trapping. The system can provide information needed to improve the performance of the light source such as beam lifetime and stability. This loss detection system was designed and installed at the SPS storage ring in 2005 [2]. However, the detected signal had a relatively large RF interference. The system was then modified in 2014 in order to better observe the beam fluctuation around the ring.

The BLM detectors are two PIN-diodes from Bergoz. They are sensitive to the minimum ionizing particle (MIP) created when a charged particle hits the vacuum chamber. These detectors generate voltage pulses when active area of the PIN-diodes is struck by the MIPs. BLM signal is counted using the coincidence technique. Figure 1 shows schematic diagram of the BLM system. The real-time loss rate at each position of the detectors is recorded every second by the NI-PXIe system and sent to the

control room. The hardware and software improvements of the BLM system are described elsewhere [3].

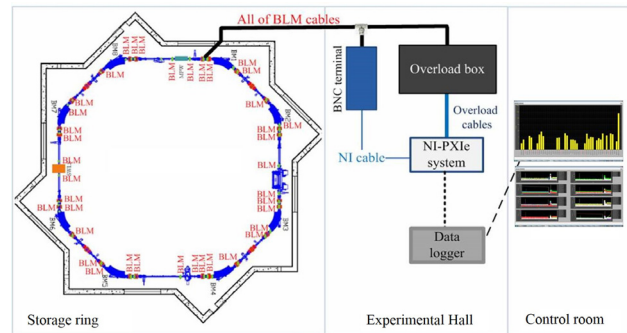


Figure 1: Sketch map of the SPS BLM system.

OPTIMAL BLM LOCATIONS

The loss rate is directly related to the beam lifetime so understanding of all associated mechanisms is necessary for determining appropriate location for BLM installation. In general, the total beam lifetime (τ) is given by three contributions as

$$\frac{1}{\tau} = \frac{1}{\tau_T} + \frac{1}{\tau_q} + \frac{1}{\tau_v} \quad (1)$$

Touschek lifetime (τ_T) originates from the scattering of electrons within the bunch which leads to longitudinal momentum deviation. If the momentum deviation is higher than the RF acceptance, the electron is lost from the system. The best location for BLM installation is thus the section of largest dispersion function.

Quantum lifetime (τ_q) arises from Gaussian energy distribution of the electron particles. It is a result of quantum fluctuations and radiation damping that lead to the loss of energy. The quantum effect may be neglected if the horizontal aperture (determined by RF voltage) is sufficiently large. Therefore, the BLM detector should be installed at the position that exhibits large betatron function where the aperture is small.

Vacuum lifetime (τ_v) originates from the collision of electrons and residual gases. If the energy loss of an electron exceeds a certain amount, it will hit the inward wall of the vacuum chamber. This is likely to happen when electron beam passing through dipole magnets.

Considering all of these contributions, the BLM detectors should be installed where the betatron and dispersion functions are high. A network of 50 PIN-diode detectors is therefore placed along the SPS storage ring at QF1, QD2, QF3, BM, and insertion devices (IDs) as shown in Fig. 2.

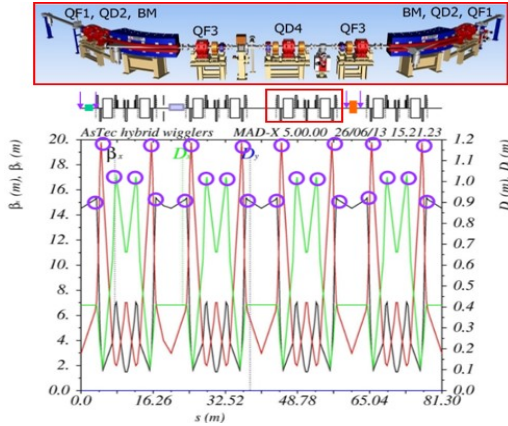


Figure 2: Betatron function and dispersion function along the SPS storage ring. The locations of BLM detectors are presented by purple circles.

OBSERVATION OF BEAM LOSS

Figure 3 shows the count rate from the beam loss monitors during a 24-hour period. The beam loss is large at the injection septum during beam injection. The loss rate goes down immediately after the injection. Moreover, the loss rate is high when the MPW gap is closing and when the SWLS is excited.

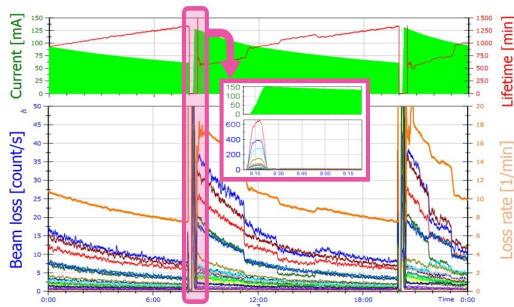


Figure 3: Machine operation status showing the beam current (green), beam lifetime (red), and count rate from beam loss monitors (all others). The beam loss signal during injection process is expanded in the pink box.

It can be seen that the measured beam loss is in agreement with the beam lifetime. The relation between loss rate (α), number of particles (N) and total beam lifetime can be expressed by Eq. 2 where the number of particles exponentially decreases with time [4].

$$\alpha = \frac{1}{\tau} = -\frac{1}{N} \frac{dN}{dt} \quad (2)$$

Machine operations with IDs

To investigate the effects of ID operation, the beam loss signals of three modes of operation are plotted together in Fig. 4. The three modes are Bare ring (without IDs operation), 2.2 T MPW (operating MPW at 2.2 T), and 4.0 T SWLS + 2.2 T MPW (operating MPW at 2.2 T and SWLS at 4.0 T), respectively. Count rate of the beam loss is generally between 1 to 25 counts/s and jumps up at the IDs due to the beam instability. The averaged loss rate with IDs operation is also higher than that of the bare ring because of the higher energy loss per turn and mismatched beam.

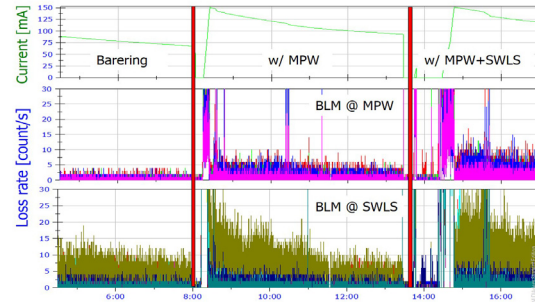


Figure 4: Beam loss for three modes of machine operation (Bare ring w/o IDs, 2.2 T MPW, and 4.0 T SWLS + 2.2 T MPW).

It should be noted that three IDs have been operated since 2013. After machine shutdown in 2015, the beam optics mismatch (betatron and dispersion functions distortion and tune shift) was compensated again using the Linear Optics from Closed Orbits (LOCO) algorithm based on MATLAB [5]. The beam optics parameters are thus nearly the same as the lattice design parameters after the correction. Table 1 lists the parameters of machine operation with IDs. The coupling decreases from 10.21% to 6.78% which results in a smaller vertical beam size and lower beam lifetime. The loss rate is also increased by 40% at the bending magnets.

Table 1: Parameters of machine operation with 4.0 T SWLS, 2.2 T MPW, and U60 before and after LOCO correction

	Lifetime (mA.min)	Tune (ν_x, ν_y)	Coupling (%)
Before cor.	75,000	4.755, 2.823	10.21
After cor.	74,000	4.766, 2.824	6.78

Vacuum pressure

At the SPS storage ring, a pressure lower than 10^{-10} Torr is desirable. The beam loss measurement will provide more information of pressure distribution because the locations of BLM detectors were carefully chosen, as discussed above. Figure 5 shows the vacuum pressure and loss rate during the beam dump. At BM4 and BM5, the loss rates are higher than that of the others due to high

pressure at these locations. In addition, it was observed that the loss rate sometimes increases when the front-end is opened for beamline commissioning. This is because the pressure becomes higher than 10^{-9} Torr. BLM system is a useful tool to investigate the vacuum problem and protect the system.

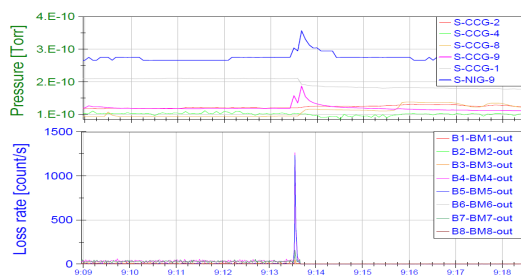


Figure 5: Beam loss and vacuum pressure during the beam dump.

Emittance Issue

In general, low emittance machine is preferable for electron particle accelerators. However, the low emittance results in high density of particles within the bunch which leads to particle loss due to the collision between them (Touschek scattering). Figure 6 shows the loss rate for three different emittances. The loss rate of low-emittance operation is higher than that of the high-emittance operation which is in agreement with the measured beam lifetime.

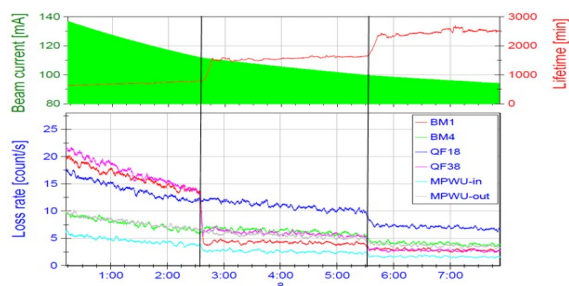


Figure 6: Beam loss for three different emittances without IDs at the beam energy of 1.2 GeV. The working point for each mode remains unchanged at $v_x = 4.768$ and $v_y = 2.813$ with different emittances.

Tune Scanning Measurement

In addition to beam loss measurement, the betatron tune of the operation was also investigated by changing the quadrupole strengths of QF1 and QD2. The tune scanning was carefully done in steps of 0.05. The working point of the ring without IDs is at the horizontal and vertical tunes of 4.768 and 2.813, respectively. The measured loss rate and tune scanning results are plotted in Fig. 7. In this measurement, the emittance is kept constant at 61 nm-rad. It is clearly shown that the loss rate is high when the horizontal betatron tunes travel across the fourth order resonance lines which cause the unstable beam. On the

other hand, the loss rate near the second order resonance is lower because the coupling values are large. Spaces in the resonance diagram with high loss rate should be avoided to prevent beam drop. In addition, an unstable beam is likely to occur when commissioning the IDs because of the betatron distortion and tune shift. The tune scanning, incorporated with the beam loss measurement, will be useful for optimizing the operation point.

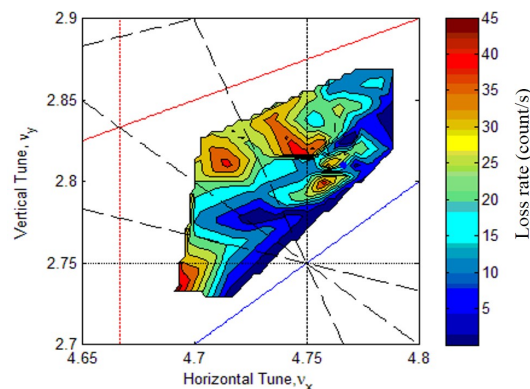


Figure 7: Beam loss rate versus tune scanning for the SPS storage ring with the emittance of 61 nm-rad.

SUMMARY

Beam loss monitor is an important tool to observe the beam instability and understand behaviors of the electron beam. Results of optics perturbation, ion-trapping, and vacuum leakage can be investigated. In addition, the good operation point in the resonance diagram can be chosen when the loss rate is plotted with the tune scanning. These results provide a possibility to improve the beam stability during machine operation of the SPS storage ring.

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