BEAM LOSS CONTROL FOR THE NSLS-II STORAGE RING *

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Abstract

The shielding design for the NSLS-II storage ring is designed for the full injected beam losses in two periods of the ring around the injection point, but for the remainder of the ring its shielded for $\leq$10% top-off injection beam. This will require a system to insure that beam losses do not exceed these levels for time sufficient to cause excessive radiation exposure outside the shield walls. This beam Loss Control and Monitoring (LCM) system will control the beam losses to the more heavily shielded injection region while monitoring the losses outside this region. To achieve this scrapers are installed in the injection region to intercept beam particles that might be lost outside this region. The scrapers will be thin (< 1Xrad) that will allow low energy electrons to penetrate and the subsequent dipole will separate them from the stored beam. These thin scrapers will reduce the radiation from the scraper compared to thicker scrapers. The dipole will provide significant local shielding for particles that hit inside the gap and a source for the loss monitor system that will measure the amount of beam lost in the injection region.

NSLS-II DESIGN AND LCM SYSTEM

The NSLS-II light source which started construction in FY2009, is a new 3rd generation light source that will replace the two operating 2nd generation light sources at BNL. It was designed to provide major improvements in the beam properties from IR to hard X-rays.

The Storage Ring (SR) is a 30 cell DBA lattice with a 15 super periods (SP), having alternating long (9.3m, LSS) and short (6.6m, SSS) straight sections. The ultra-low emittance ($\leq$1nm) is obtained not from breaking the achromatic condition for the lattice, but by increasing the synchrotron radiation damping using damping wigglers, DW, (3- 7m 1.8T wigglers) in the achromatic straights to reduce the lattice emittance in steps, in addition to the user undulators in the SSS's[1].

In order to maintain the high brightness for the users, the SR is designed for top-off operation with a minimum injection pulse frequency of one injection per minute, to provide a $\leq \pm$1% beam current stability. This requires a full energy booster capable of high injection efficiency.

The SR radiation shield consists of 2-cells (injection and the downstream cell) of heavy concrete shielding capable of shielding the experimental floor from the loss of the full top-off injection beam current. The remainder of the ring will be shielded for a beam loss rate of up to 1/12th of the top-off injection rate at any one location in the ring. As a consequence of this shielding decision a Loss Control and Monitoring (LCM) system has been specified that will control and monitor local beam losses in all of the accelerators systems to less than the shielding design levels. The LCM will consist of components that will:

1. monitor and limit the beam power losses from the accelerators and transport lines,
2. control the major beam losses in the SR to the heavily shielded Injection Region (INR), and
3. monitor the SR beam losses in the INR and account for losses in the remainder of the SR.

The LCM system will monitor the beam current losses (difference between two consecutive current monitors) times the energy of the system transporting that beam (i.e booster dipole or transport dipole field or linac RF gradient) to determine the beam power lost. If the lost beam power exceeds the shielding design level at that location, then alarms will be issued to operators and the accelerator control systems that action is required to lower level in order to continue injection. If corrective action isn't taken within a specified time period, that insures potential radiation exposures don't exceed administrative levels, then the LCM could prevent continuing injection. The decisions made by the LCM are not as critical, as the credited Personal Protective System (PPS) and therefore will be made in a non-safety rated control computer that will stop injection should the system fails.

SR BEAM LOSS CONTROL

In order to control the SR beam losses to the more heavily shielded INR, a set of five scrapers are planned in this region. They include 3 horizontal scrapers, 2-near peak dispersion (Hscraper1 & 2) and one in zero dispersion but maximum β_x location (HscraperX), and 2 vertical scrapers (Vscraper1 & 2) located at large β_y and with a phase shift between them of near 90° ($\Delta\varphi_y$ ~67°). The locations of the scrapers together with their Twiss parameters for the NSLS-II SR are shown in Figure 1. The scrapers are installed upstream of dipole magnets, since the scrapers are thin enough to degrade the beam energy (but not stop them) and the subsequent dipoles will deflect the penetrating lower energy beam particles into the dipole magnets as a self-shielded beam dump, as well as, for a source of lost beam signal for the Cerenkov Beam Loss monitors (CBLM)[2], which provide the required beam loss in the injection region verification measurement.

The expected impacts of each of these scrapers on controlling the various mechanisms for beam loss are listed in Table I. The scrapers Hscraper1 & 2, in the dispersion region are listed for the inner (δ<0) and outer (δ>0) blades separately while the others are combined effect. Since the inner blades of Hscraper1 and 2 are

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expected to intercept the largest number of beam loss mechanisms, the remaining analysis will deal mostly with their impact.

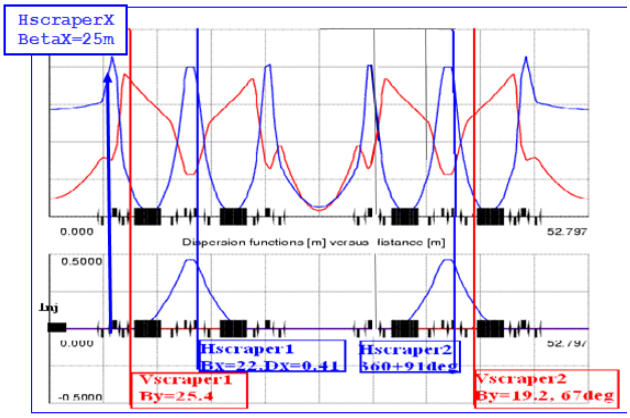

Figure 1: SR injection super period with Horizontal (blue) and Vertical (red) scraper locations and Twiss functions.

Table I: Beam loss mechanisms and the scraper which will have the largest impact on controlling that loss.

Beam Loss Model	Hscraper1&2 Inner Blade	Hscraper1&2 Outer Blade	HscraperX Both Blades	Vscraper1&2 Both Blades
RF Trips off	Yes	No	No	No
Beam Dump Instab.	Yes Longit.	Maybe	Yes Horiz.	Yes Vert.
Touschek $\delta < 0$	Yes	No	No	No
Touschek $\delta > 0$	Yes % Synch	Yes	No	No
Gas Bremsstrahlung	Yes	No	No	No
Gas Elastic Scatter	No	No	Yes (DW's?)	Yes (IVU's?)
Injection $\lvert\delta\rvert > 0$	Yes	Yes	No	No
Inject. Steer. X or X'	Maybe	Maybe	Yes	No
Inject. Steer. Y or Y'	No	No	No	Yes
Timing offset	No	No	No	No

The requirement for the LCM system to control where the majority of the beam is lost in the SR and to verify those beam losses, has resulted in a scraper design similar to those used in NSLS [3], that uses relatively thin scraper blades that will degrade the energy of beam particles hitting the scraper. If the scraper blade is too thin some beam particles will only loose a small energy due to ionization loss and might continue to circulate in the SR. If the blade is too thick too much of the electron energy is showered into gamma rays and low energy electrons that will not be dumped into the dipole and therefore not provide the beam loss signal needed to verify the fraction of the beam lost in the injection region. It would also require significant local shielding to be added to avoid exceeding the design loss levels for the shielding even in the injection region. A 10mm (0.7 Xrad) thick copper blade was chosen as a reasonable compromise and its fractional electron penetration is shown in Figure 2. The fraction of electrons losing less than 20% of their energy is about 14%, at this energy loss the electrons will be bent to the edge of the vacuum chamber (VC) at the exit of the dipole, while those losing only 10% will hit the VC at the next quadrupole magnet.

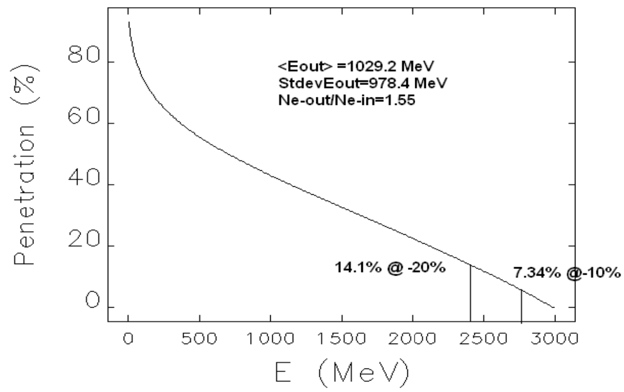

Figure 2: The fraction of electrons penetrating the scraper having energy above E, for 3 GeV electrons incident on a 10mm thick Cu scraper.

SCRAPER IMPACT ON BEAM LOSS

To estimate where the electrons penetrating the scraper are lost in the SR, the program Shower [4] was interfaced to the Elegant tracking program [5]. The inner blades for Hscraper1 & 2 were inserted from the inner VC wall to X=-19mm from the centreline. Particles with the SR emittance distribution were generated on axis at the injection septum but given a momentum offset δ=-4.2%.

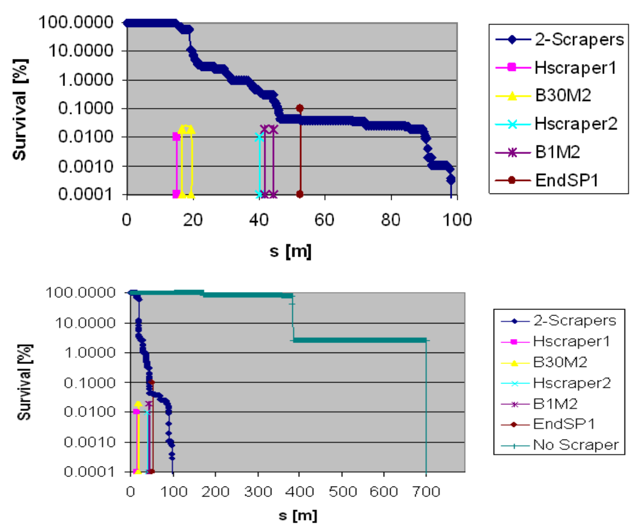

Figure 3: Survival of beam particles, with δ=-4.2%, versus longitudinal coordinate that hit Hscraper1 & 2 inner blades at X=-19mm in the INR (Top) and for the ring (bottom), also shown is beam survival without the scrapers. The locations of the scrapers, subsequent dipoles and the end of INR, SP1 are noted.

With this offset particles would just (centroid 0.1mm inside edge) hit the Hscraper1, but as a result of the emittance and nonlinear dispersion some particles miss the first scraper but hit Hscraper2, as a result of the 90° phase shift between them. Particles that hit either scraper are passed to the Shower interface. Of the output particles from Shower, only the electron with the greatest energy is kept and passed back to the lattice for continued tracking. Particles are lost when they hit the VC wall at any point in the lattice. The fractional particles surviving are shown in Figure 3, together with the surviving fraction if the scrapers were not present. Only 0.04% of the particles survive past the heavily shielded injection region with the scrapers present and none after the SP2 of the lattice. Without the scrapers, the losses would have occurred around the ring, mostly in the locations of the damping wigglers. This demonstrates effective control of the beam losses for: RF dumps, gas Bremsstrahlung, low momentum injection and the low momentum particle from Touschek scatters. A larger fraction of the Touschek scatters might be controlled if the blade was inserted further, but this will start to reduce lifetime resulting from Touschek scatters that occur in the dispersion regions around the ring that would not have been lost on the existing momentum apertures. This is shown in Figure 4 where the calculated Touschek lifetime is plotted versus the inner blade position, which shows even slight reduction of lifetime even at -25mm. The plan is that during commissioning of the NSLS-II SR, the position will be determined for each of the scraper blades which provide a significant control (shift of the beam loss point to the INR) without significantly reducing the beam lifetime. However, only the inner blades of the Hscraper1&2 are planned to be a critical part of the LCM system. They will be locked in their determined position, in order to allow high current operation of the SR.

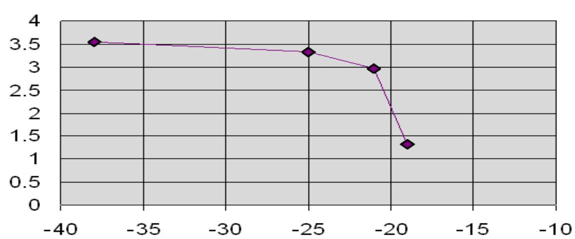

Figure 4: Variation of Touschek Beam Lifetime in hours versus the Hscraper1 & 2 inner blade position in mm, for 500mA operations and 2.5MV RF voltage.

Studies of the impact of the outer blades of Hscraper1 &2 shows their impact is not as direct since beam particles must have $\delta>0$ to hit them, then the low energy loss particles may survive multiple turns. Figure 5 shows the impact of the outer blades of Hscraper1 & 2 inserted to X=19mm, where 0.2% of the particles survive the first pass around the lattice but only 0.01% survive the third pass. Despite this multi-turn effect, these scraper blades do control the major (99.8%) of the beam loss to the INR.

CONTROLLING RF BEAM DUMPS

NSLS-II will have superconducting RF cavities which cannot be turned off too rapidly due to reflected beam power inducing high fields which could quench the cavities. Therefore it is planned to dump beam by shifting the RF cavity phase from the stable to the unstable fixed point, $\Delta\varphi\sim-150°$, over about 100µsec, before ramping down the forward power. The impact of this phase shift on controlling the beam loss location with the inner blades of Hscraper1 &2 has been studied. The beam is lost on the scraper blades, inserted to X=-23mm, about 500µsec after the phase shift. Figure 6 shows this beam loss occurs entirely just downstream of the scrapers, in the INR, preventing losses outside this region.

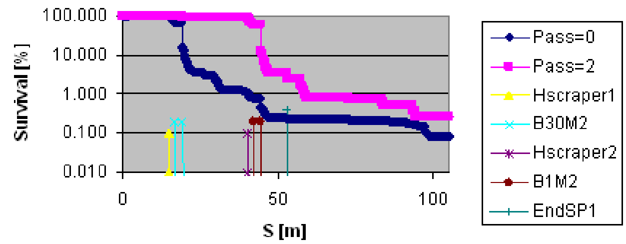

Figure 5 Survival of beam particles with δ=4.95% over 3 turns with the outer blades of Hscraper1 &2 inserted to X=19mm. Pass 2 shows the survival of the 0.2% of the particles that survive the first two turns, with 0.01% of the initial particles surviving the 3rd turn.

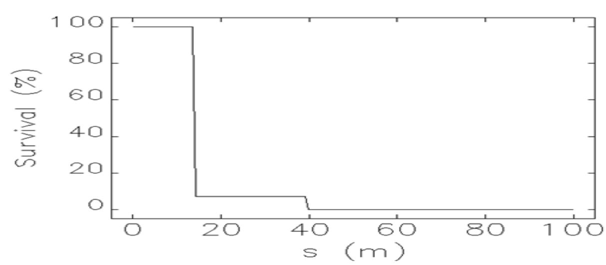

Figure 6: Shows the location of the beam particle losses at the Hscraper1 & 2 in the INR, for inner blades at X=-23mm ($\delta\sim$ -5.6%) resulting from a beam dump using the RF phase shift technique described in text.

SUMMARY AND FUTURE WORK

The use thin horizontal scraper blades has been shown to effectively control the beam losses to the INR for the NSLS-II SR. This will also provide a well-defined beam loss signal from CBLM's in the dipoles and quads, as well as for reducing the need for local shielding of the scrapers. Future work will show the impact of using the vertical scrapers and the fraction of Touschek losses that will be controlled by the horizontal scrapers.

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