

## BEAM CONTAINMENT SYSTEM FOR NSLS-II\*

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### Abstract

The shielding design for the NSLS-II will provide adequate protection for the full injected beam loss in two periods of the ring around the injection point, but the remainder of the ring is shielded for lower losses of  $\leq 10\%$  full beam. This will require a system to insure that beam losses don't exceed these levels for a period of time that could cause excessive radiation levels outside the shield walls. This beam containment system will measure, provide a level of control and alarm indication of the beam power losses along the beam path from the source (e-gun, linac) thru the injection system and the storage ring. This system will consist of collimators that will provide limits to (and potentially to measure) the beam miss-steering and control the loss points of the charge and monitors that will measure the average beam current losses along the beam path and alarm when this beam power loss exceeds the level set by the shielding specifications. This will require some new ideas in beam loss detection capability and collimation. The initial planning and R&D program will be presented.

### NSLS-II DESIGN AND SPECIFICATIONS

The NSLS-II light source, which has started construction in FY2009, is a new 3<sup>rd</sup> generation light source that will replace the two operating 2<sup>nd</sup> generation light sources at BNL. It has been designed to provide major improvements in the existing beam properties from IR to hard X-rays, with leading edge electron beam properties.

The Storage Ring (SR) is a 30 cell DBA lattice with a super periodicity (SP) of 15, with alternating long (9.3m, LSS) and short (6.6m, SSS) straight sections. The ultra-low emittance ( $\leq 1\text{nm}$ ) is obtained not from breaking the achromatic condition for the lattice, but by using a novel approach of increasing the synchrotron radiation damping using damping wigglers, DW, (3-8 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, in order to maintain a  $\pm 1\%$  beam current stability. This requires a full energy booster capable of high injection efficiency. Table I lists some of the beam parameters of the NSLS-II accelerators required for top-off operations.

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

1/12<sup>th</sup> of the top-off injection rate at any one location in the ring. As a consequence of this shielding decision a Beam Containment System (BCS) has been specified that will control and monitor local beam power losses in all of the accelerators systems to less than the shielding design levels. The BCS will consist of components that will:

1. monitor and limit the beam power losses from the accelerators and transport lines
2. control a major part of beam losses in the SR to the heavily shielded injection region and
3. monitor the SR beam losses in the injection region and account for losses in the remainder of the SR.

Table 1: The NSLS-II accelerators beam parameters

<b>Storage Ring</b>	
Energy	3 GeV
Circumference	791.96 m
Emittance	0.6- 2 nm-rad
Harmonic / Ops. Bunch Number	1320 / 1080
Average Current	500 mA $\pm$ 1%
Operational charge per bunch	1.3 nC
Maximum Top-Off rate	$\leq$ 1 / minute
Injection Rate for 3 hr Lifetime	7.3 nC/ minute
<b>Booster Ring</b>	
Energy	0.2 – 3 GeV
Circumference	158 m
Average Current / Max. charge	20 mA / $\leq$ 15 nC
Emittance	40 nm-rad
Maximum rep. rate	1 Hz
<b>Linear Accelerator</b>	
Energy / Freq	200 MeV / S-Band
Repetition Rate	$\leq$ 10Hz
Maximum Average current	$\leq$ 150 nA
Emittance	$<$ 50 $\mu\text{m}$ -rad

### BCS SPECIFICATIONS [2]

The BCS specifications for each of the accelerators and beam transport lines are based on an analysis of the severity of the potential radiation exposure for a particular beam loss scenario which exceeds the shielding design beam loss specification. For the injection systems, the severity of the full beam power lost at any point could be high enough that engineering solutions maybe required. For example, if the full beam power of the booster were lost at any point other than the extraction region, the area above the booster shielding berm would become a high radiation area. The engineering solution is to fence off this area and post a remote area radiation monitor at this location.

The BCS system will monitor the beam current loss (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

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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 in order to continue operations at that level. If corrective action isn't taken within a specified time period, that insures potential radiation exposures don't exceed administrative levels, then the BCS could prevent injection from continuing. The decisions made by the BCS are not as critical, as the Personal Protective System (PPS) and therefore will be made in a non-safety rated micro-computer that will automatically stop injection if the system fails.

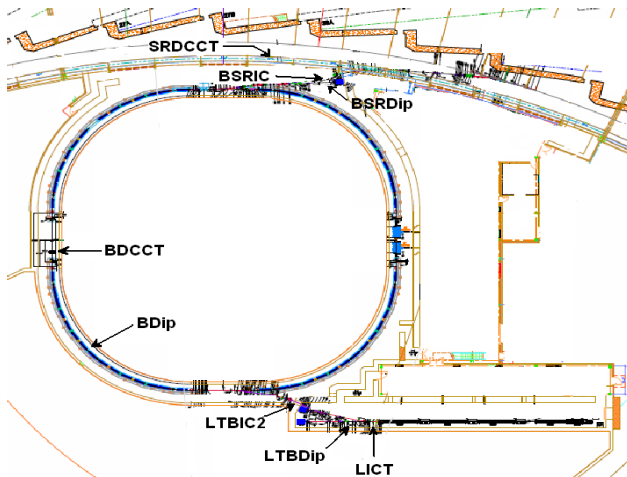


Figure 1: SR Injection System with BCS components

Figure 1 shows some of the components of the BCS for the injection system. The worst case beam power loss that has been analyzed is a major fraction of the beam current lost in the booster at full energy. This would be determined by sampling the booster current (BDCCT) at full energy (top field of the booster dipole, BDip) and comparing with the extracted beam current (BSRIC). This type of decision will be made for each stage of the injection process and alarms sent when design levels are exceeded or are being approached. The analysis of full injection beam losses in the SR doesn't result in as high a potential radiation level but will have a risk of greater exposure due to the greater occupancy of the experimental floor. Therefore, in the SR the BCS must insure local losses don't exceed the design level, which depends on the location of the beam power loss. The BCS approach for the SR will consist of the latter two components listed above, and will insure that the shielding design loss levels aren't exceeded during operational periods. These loss levels can be exceeded during non-operational periods (i.e. commissioning and machine studies) or during operations under administrative control.

### SR BEAM LOSS CONTROL

The BCS is planned to capture a major portion of the beam power lost in the heavily shielded injection region using beam scrapers. It is planned to provide five scraper

locations in this region, each with a pair of opposing blades to define the beam aperture channel for the circulating beam. The locations of the scrapers are shown in Figure 2 and were chosen to be near the location of maximum amplitude of the particle coordinates: two vertical scrapers (Vscraper1 & 2) are at large  $\beta_y$  locations with  $\sim 70^\circ$  phase shift between them, one horizontal scraper (HscraperX) is located at a high value of  $\beta_x$  and the two horizontal (Hscraper1 & 2) are at high dispersion locations with  $90^\circ$  horizontal phase shift between them.

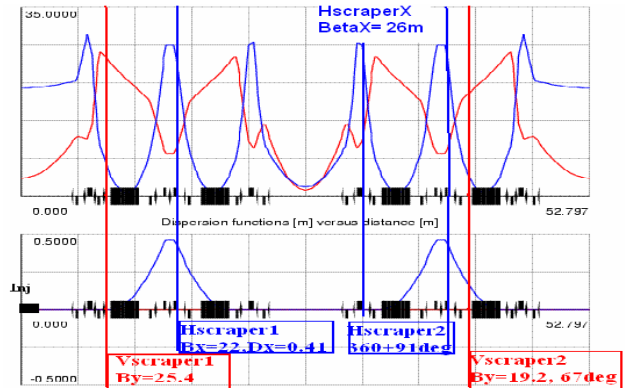


Figure 2: SR Injection super period with Horizontal (blue) and Vertical (red) scraper locations and Twiss parameters.

The later two, Hscraper1 and Hscraper2 are the only ones planned for use at high current operations, and only the inner blades are being considered here. They will be inserted to  $\Delta X \sim -20\text{mm}$  and will set a closed orbit momentum aperture of  $\delta \geq -5\%$ . This will intercept low momentum particles from beam dumps, Bremsstrahlung, instabilities and the low momentum tail of the Touschek scattered electrons. The high energy Touschek scattered particles, if they aren't lost within a few turns, on the synchrotron radiation absorbers around the ring, will be decelerated by the RF ( $\sim 60$  turns) to lower energies and intercepted at these inner blades.

The scrapers are designed to be only 10mm thick of copper, which will absorb only enough beam energy to insure the subsequent dipole will bend the particles out of the vacuum chamber in the injection region. The fraction of the electrons penetrating one scraper is shown in Figure 3. For electrons with greater than 15% of their energy lost in the scraper, they will be bent to the inner wall of the vacuum chamber inside the dipole magnet. The 10% of the incident electrons that penetrate with less than 15% energy loss, they will be lost on the vacuum chamber downstream of the dipole. The 0.5% that have  $< 1\%$  energy loss, will hit the second scraper where they undergo additional energy loss and be bent out of the vacuum chamber. The residual penetration of electrons which might circulate is  $< 10^{-5}$ , as shown in Figure 4. The thin scraper will produce very low level of radiation and neutron off the scraper, requiring very little local shielding. The beam that is dumped in the dipole will see considerable self-shielding by the dipole yoke itself, requiring less local shielding [3].

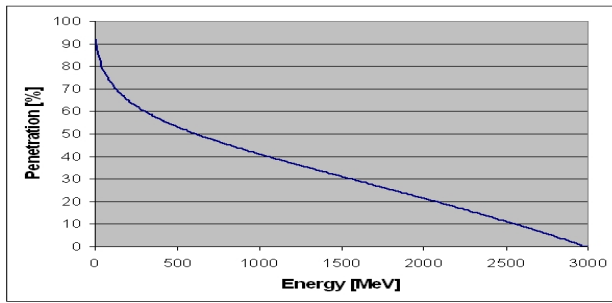


Figure 3: 3 GeV electron penetration through 10mm Cu.

The estimates of the fraction of lifetime beam losses intercepted by the two horizontal scrapers at  $\delta = -5\%$  closed orbit error are still being calculated. Although the two scraper blades at this momentum aperture are the only ones being planned for operations, the additional scrapers will be available for empirical studies with beam once the NSLS-II is operational. They will be studied to see if they will intercept a significant fraction of the remaining beam losses, without reducing the lifetime further or driving instabilities due to HOMs impedance. The vertical scrapers may provide some additional protection from radiation for the in vacuum undulators (IVU's) due to elastic gas scattered particles. However, since this induces a vertical betatron oscillation with 16 periods per turn, the scraper maybe ineffective in reducing this radiation loss on the IVUs without significantly reducing the beam lifetime.

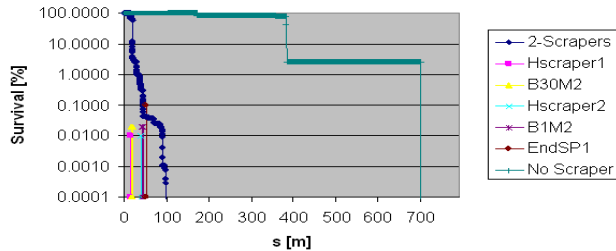


Figure 4: Survival of particles hitting the scrapers compared to losses without the scraper for  $\delta = -4.2\%$

## SR BEAM LOSS MONITORING

The use of beam scrapers to intercept beam losses in the injection region, was deemed insufficient and it was suggested that beam losses in the rest of the SR needed to be monitored. The beam charge loss rate (at SR energy) will be determined from DC beam current measurements ( $I_o$ ), plus any injected charge ( $Q_{inj}$ ), during injection periods will be given by:

$$Q'_{loss} = \{Q_{inj} - [I_o(t + dt) - I_o(t)] * T_o\} / dt \quad (1)$$

where  $T_o$  is the SR revolution period.

If the amount of charge loss that hits the scraper can be measured, and if the remaining unaccounted charge loss is  $< Q'_{sdl}$ , the SR shielding design limit, then it doesn't matter where it is lost. Even if this limit is exceeded for a short time period, the average over administrative time

periods could be maintained below this limit, by reducing the injection rate, as a last resort.

Several methods have been considered for measuring this charge hitting the scraper directly and are still being considered. Beam loss monitor studies from the NSLS [4] showed that scintillation detectors outside the variable absorption of magnets and other components, made correlation with charge loss difficult. Simplifying the radiation field by going closer to the loss point and measuring only the electron component of the shower showed the greatest promise to achieve this goal.

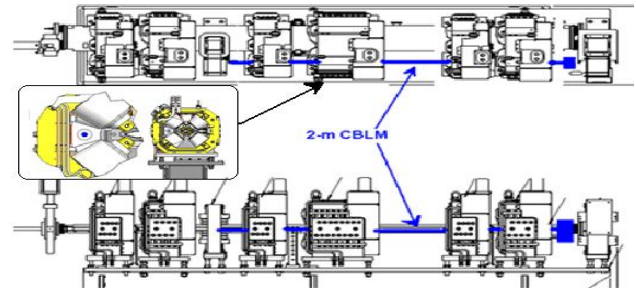


Figure 5: Two meter long CBLM placed inside quadrupole and sextupole magnets on a SR girder

The approach that appears most promising is to measure the shower electrons after the dipole magnet bends the electrons that hit the scraper into the vacuum chamber wall downstream from the dipole. The high energy charged particles ( $e^-$  and  $e^+$ ) from this shower will have a small angular spread and a Cerenkov radiator placed close to the vacuum chamber (inside the magnet yokes) will provide a clear signal proportional to the initial charge loss, with a large variance of the signal for single particles. One approach being studied, Cerenkov Beam Loss Monitors (CBLM), is to place a quartz rod close to the vacuum chamber wall on the inside of the ring, see Figure 5, in between the coil of quadrupole and sextupole magnets as shown in inset. A similar CBLM can be placed in the gap of the dipole magnet to measure the light from  $e^-$  that hit the scraper and are bent by the dipole to the chamber wall. The number of CBLM detectors isn't determined, but placing one on every girder could monitor if any local loss rate (to the girder level) exceeds the design loss limit.

An R&D effort has begun to study this type of CBLM but initial calculations of the shower process show the signal from the charged particles in the CBLM will be large enough that less expensive photodiode detectors can be used, instead of PMTs. Calculations of the output signal per initial  $e^-$ , show a well define enhancement of  $\sim 2-10X$  the signal for an  $e^-$  at normal incidence.

## REFERENCES

- [1] S. Ozaki, et.al., proceedings PAC07, p. 77(2007).
- [2] BCS has recently been renamed Loss Control and Monitoring system to better describe its function.
- [3] P.K.Job, et. al., proceedings RADSynch09, p. (2009).
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