BEAM LOSS MONITORS FOR NSLS-II STORAGE RING*

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Abstract

The shielding for the NSLS-II storage ring will provide adequate protection for the full injected beam losses in two cells of the ring around the injection point, but the remainder of the ring is shielded for lower losses of <10% top-off injection beam current. This will require a system to insure that beam losses do not exceed levels for a period of time that could cause excessive radiation exposure outside the shield walls. This beam Loss Control and Monitoring system will have beam loss monitors that will measure where the beam charge is lost around the ring, to warn operators if losses approach the design limits. To measure the charge loss quantitatively, we propose measuring the electron component of the shower as beam electrons hit the vacuum chamber (VC) wall. This will be done using the Cerenkov light as electrons transit ultra-pure fused silica rods placed close to the inner edge of the VC. The entire length of the rod will collect light from the electrons of the spread out shower resulting from the small glancing angle of the lost beam particles to the VC wall. The design and measurements results of the prototype Cerenkov BLM will be presented.

NSLS-II DESIGN AND LCM SYSTEM

The NSLS-II light source started construction in FY2009, is a new 3rd generation light source that will replace the two operating 2nd generation light sources at BNL. It has been designed to provide major improvements in the existing 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 rather 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 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 beam current stability $\leq \pm$1%. This requires a full energy booster capable of high injection efficiency.

The injection region (INR) radiation shield of the SR consists of 2-cells with 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 is 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 [2]. For more details on LCM system see Ref. [3].

BEAM LOSS MONITORING IN SR

The thinner radiation shield around the SR resulted in a requirement for the LCM system to 1) limit a majority of the beam losses to the INR and 2) verify that the beam losses around the rest of the ring don't exceed design levels for significant time periods that could cause radiation exposures above administrative control levels. The first requirement is handled by installing five scrapers within the INR to control where these beam losses occur [3]. A critical part of the design of these scrapers is that they provide a beam loss signal to measure the actual charge intercepted. The amount of the total beam charge lost that is not measured to be lost in the INR will be attributed to losses in the remainder of the ring, which will then be tested to assure it doesn't exceed the shielding design levels.

The SR beam charge loss rate in a time dt, will be determined from DC beam current measurements (I_o), plus any injected charge (Q_{inj}), and is given by:

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

where T_o is the SR revolution period.

In between injection pulses ($Q_{inj} = 0$), Eq. (1) gives the beam lifetime loss rate. If the amount of charge loss that hits the scrapers in the INR can be measured, then an estimate of the beam charge loss outside the INR (Q_{SRNINR}) is the remaining unaccounted charge loss. The Cerenkov Beam Loss Monitor (CBLM) is designed to measure the beam charge that hit the scraper and deflected by the subsequent dipoles into the CBLM's [3]. There will be seven CBLM's in the INR with 3 in dipole magnets and 4 in quadrupole magnets. Several (2-3) will make redundant measurements of the charge loss (Q_{CBLMi} for i=1:7) from one scraper. Since the CBLM signal will be statistics limited, these redundant measurements will be weighted to improve the resolution of the beam charge lost on one scraper. To further improve this estimate of missing charge, fast neutron beam loss monitors (NBLM) are planned to measure the injection charge lost in the injection septum (Q_{NBLM}) of the SR. Then the SR non-INR charge lost rate, Q'_{SRNINR} , is given by:

$$Q'_{SRNINR} = Q'_{loss} - \left[\sum_{i=1,7} Q_{CBLMi} + Q_{NBLM} \right] / dt \qquad (2)$$

If this $Q'_{SRNINR} < Q'_{SRDL}$, the SR shielding design limit, then there is little concern where it's lost. Even if this limit is exceeded for a short time period, the average over administrative time periods could be maintained below this limit, if operators are aware (via alarms) that this

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level needs to be reduced. As incentive, the operator will be given a time period to correct the loss rate before the Top-Off injection pulses are suppressed and the SR current begins to drop (a control of last resort).

CERENKOV BEAM LOSS MONITORS

In electron rings one difficulty in measuring local charge loss using scintillators or ionization chambers is the gamma ray signal from distant beam loss locations. The use of Cerenkov light from high energy electrons passing through a glass rod will eliminate this sensitivity, as well as that from low energy electrons whose direction is greatly affected by the magnetic fields of the accelerator lattice.

The Cerenkov light is emitted by a relativistic electron passing thru a medium with index of refraction, n(λ), if its velocity is $\beta_t > 1/n(\lambda)$. The number of photons emitted per unit wavelength, λ, and per unit path length, dx is given by [4]:

$$\frac{d^2N}{d\lambda\, dx} = \frac{2\pi\alpha}{\lambda^2}\sin^2(\theta_c) \qquad (4)$$

where $\theta_c = \cos^{-1}[1/(n(\lambda)^*\beta)]$ is the emission angle of the photons relative to the electron direction. The greatest number of photons is in the UV spectral range.

High energy physics experiments have used ultra-pure fused silica as radiation resistant radiators that transmit light down to wavelength of λ ~180nm. For this material $n(\lambda)$ ~1.458, β_t ~0.68 (E_t~0.62 MeV) and θ_c ~ 46º,however the light output is down by 20% or more for E <1.2MeV. These experiments were looking for single particle detection and use photomultiplier tubes (PMT) which are expensive, require high voltages and have only 10-20% quantum efficient (QE) photocathodes. Recent advances in photodiode (PD) technology have produced QE >50% in the UV range. Estimating the signal for one electron per turn passing through a 1cm radiator rod at right angle and half the photon emitted incident on a UV PD's gives S/N ~0.25. External gain could be used to make the signal detectible as pulses without saturating the signal output when a large beam loss occurred, something not possible when the PMT gain is high. When a beam particle hits the scraper and is bent into the chamber wall of the dipole, as shown in Figure 1, the electron will shower in the Aluminium VC creating additional electrons with a spectrum of energies and angles that will provide additional signal from the added electrons and their increased path length in the radiator. To estimate the PD signal this shower process needs to be understood.

Calibration of the CBLM signals to absolute charge loss/sec will be done using the scraper dominated reduced lifetime to measure local beam loss rate that will hit the CBLM in the dipole and quads downstream of the scraper. The CBLM signal will then scale with the Q'_{loss} signal of Eq. (1). This will be used to calibrate the CBLM's on a periodic basis, which will enable their use over a significant range of absorbed dose, even with radiation induced attenuation of the light in the rods.

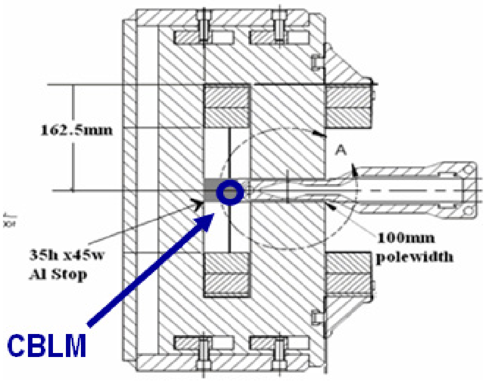

Figure 1: SR dipole magnet with CBLM and Al absorber insert adjacent to inner wall of the vacuum chamber.

ELECTRON SHOWER IN VC WALL

The NSLS-II VC has an inner Al wall that is ~25mm thick with a 10mm water channel. The physics of the shower process was studied using the Shower [5] interface to the EGS4 [6] program. A beam of 3 GeV electrons was directed into the inner VC wall with grazing incidence angles from 1 to 7°. The number of electrons passing through the inner wall are calculated and propagated to a 10mm quartz rod 25mm from the VC edge. The path length for electrons that pass through the rod with energies greater than 10MeV were calculated. The product of the number of these electrons generated times their path length was averaged for a large sample of incident particles to compute the signal enhancement factor for the initial electron at normal incidence signal computed above. This enhancement factor is shown in Figure 2 which increases the S/N per electron lost per turn to >2 for glancing angles >3°. The longitudinal coordinate and path length distributions for electrons in the 10mm radiator generated by 3 GeV electrons incident on the inner VC at a 3° glancing angle are shown in Figure 3.

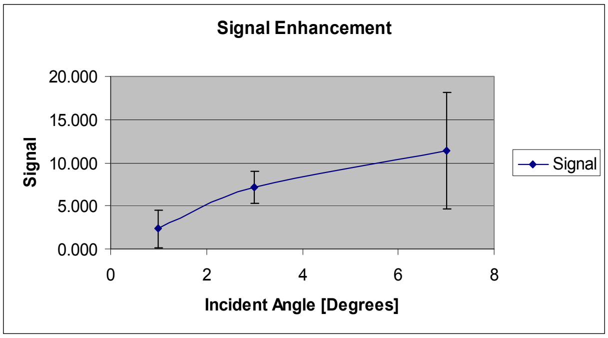

Figure 2: Increase in Cerenkov light signal for 3 GeV electron shower incident on the inner VC wall as a function of grazing incidence angle to the chamber, compared to the electron at normal incidence on the rod.

Based on these shower studies the CBLM design was increased to 25mm diameter rod. This will increase the fraction of electrons seen by the rod and the path length in the radiator rod. To capture more electrons from the shower, the rod length will be increased to 2meters. This will result in an S/N >2 for all angles. The output coupling is still being designed but will propagate the light to a location under the magnet girder and out of the radiation plane, in order to protect the PD module.

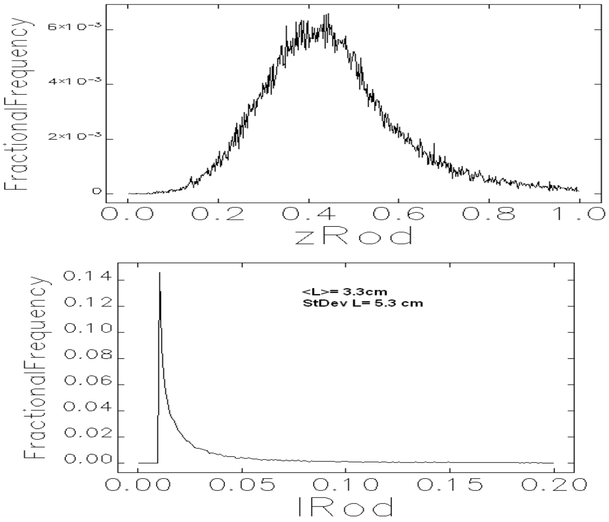

Figure 3: Longitudinal (top) and path length (bottom) for shower electrons in a 10mm radiator rod for 3Gev electrons incident at 3° angle to the 25mm Al VC wall.

In addition to locations in the dipole, CBLM's will be installed in the quadrupole and sextupole magnets downstream from these dipoles. This will detect the highest energy electrons off the scraper, as well as losses when the scrapers are not in, from the maximum dispersion or beta function locations of the ring. These can be measured using the same CBLM by inserting the radiator rod between the coil packs of the quadrupole and sextupole magnets, as shown in Figure 4.

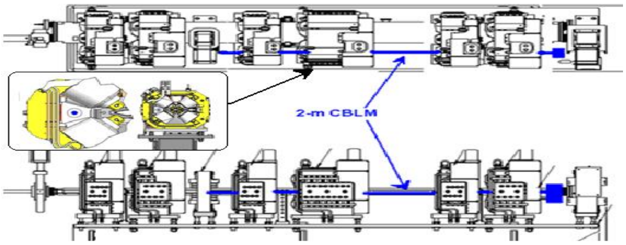

Figure 4: Two meter CBLM placed between the coils of the quadrupole and sextupole magnets on a SR girder.

PROTOTYPE CBLM TESTING

The prototype CBLM consisted of a 10mm OD rod, 1-m long of Suprasil 2B [7] mounted in an Aluminium tube and coupled through air to a Hamamatsu PD module[8] in an Al and Pb box for shielding, as shown in Figure 5.

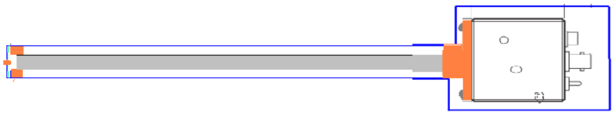

Figure 5: Schematic of prototype CBLM with a 91.5cm long radiator rod and PD module with Al light shield.

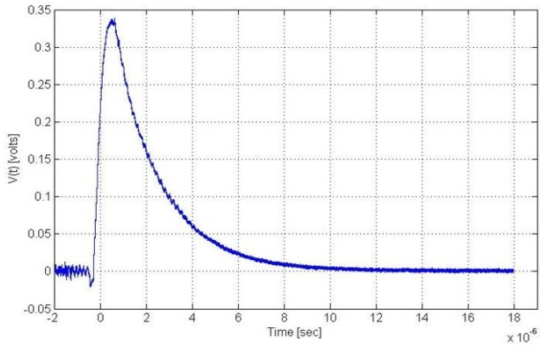

Figure 6: CBLM signal for ~2nsec pulse of 120 MeV electrons at nomal incidence to the 10mm radiator rod.

This unit was tested in a Co60 source to measure the fluorescence signal that gamma rays produce in the rod and PD module itself. A low level of 2mV/1x10^{11} γ/sec signal was observed. When inserted into a 120MeV pulsed (~2nsec) electron beam of ~2x10^{8} e^{-} per pulse, the Cerenkov light signal was ~400mV, as shown in Figure 6.

The next task will be to install the CBLM in the NSLS Xray ring and measure the CBLM signal versus the scraper controlled local beam loss rate, as proposed for NSLS-II. Once calibrated by the scraper, the CBLM signal will measure the local loss rate arising from lifetime or other loss mechanisms in that region.

SUMMARY AND FUTURE WORK

The CBLM will measure the local beam loss rate originating from the inserted scraper, by measuring the electron component of the shower due to beam hitting the vacuum chamber. This principle can also be used at other locations where the normal lifetime or instabilities driven losses hit the VC aperture. In this case calibration will require an alternative to the scraper induced local loss rate method, a work in progress. For NSLS-II the LCM scrapers will be the major loss point for high currents operations, and the presently planned CBLMs will verify the amount lost in the INR.

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