BEAM LOSS MONITORS IN THE NSLS STORAGE RINGS*

S. L. Kramer# and M. Fedurin
BNL, Upton, Long Island, NY 11973 USA

Abstract

Beam loss monitors (BLM) have been used for more than two decades in the VUV ring at the NSLS. These have proved useful for optimizing injection and operation of the ring. Recently similar monitors have been installed in the Xray ring and are being used to better understand injection, as well as operation of the ring. These units have been compared with the Bergoz BLMs, which have been mostly useful for understanding operating beam losses.

INTRODUCTION

The National Synchrotron Light Source (NSLS) has two electron storage rings that have been in operation since 1983. The VUV ring is a low energy ring with a critical energy of ε_c ~0.6 KeV, which as a result of the low energy synchrotron radiation was built without an radiation shield tunnel, requiring careful understanding and reduction of the radiation losses during injection. The Xray ring is higher in energy with a radiation tunnel and less radiation loss issues. The free standing radiation shield walls and local shielding of the VUV ring protect user from the bremsstrahlung radiation during injection and low lifetime operations. A consequence of this limited shielding, Beam Loss Monitors (BLM) have been an important part of the beam diagnostics for this ring and have been online since about 1988. These BLM's include ionization chambers (IC), scintillation detectors (SD) and more recently diode detectors (DD). See reference [1] for summarizes of the NSLS rings properties.

RADIATION MONITORS

The goal for these radiation monitors is to measure the local charge lost from the ring either during injection or stored beam operation and hopefully point out the cause of the lost beam and how to minimize the loss. Most monitors will measure both the electron and γ-ray component of the shower when electrons hit the vacuum chamber or another obstruction. The detector signal for a point source of beam loss will depend on the local (differential) charge loss rate
α_i, where $dQ_e/dt = Qe * \alpha_i$ and Q_e is the circulating plus injected charge, ($I_o*T_o + Q_{inj}$). The current signal in a detector with area A, a distance r, from the source point can be expressed by

$$I_s(t) = Q_e(t)\alpha_i\left[R_e(r,\theta,\phi) + R_\gamma(r,\theta,\phi)\right]\tfrac{A}{r^2}$$

where $R_e(r,\theta,\phi)$ and $R_\gamma(r,\theta,\phi)$ are the production, attenuation and detector response terms for e^+, e^- and γ-rays in the material and detector. If the beam loss is distributed over many loss points the detector signal will be the integral over these locations each with a varying production and attenuation of electrons and gamma rays, but the geometric term r^{-2} will reduce the distant radiation source point signal. The monitor should be designed to measure predominantly this local rate. The integral of the local loss rates around the ring is just the total rate or the inverse of the beam lifetime (τ), measured from the current decay. The calibration of the local loss rate is difficult, but placing the detectors close to the source point and minimizing the material production and attenuation of the primary radiation from the loss point will improve this ability. Using the directionality of the high energy bremsstrahlung radiation (HEBR) from the loss point and attenuating the backscatter from other loss points can make the signal from these detectors more quantitative.

IC detectors will detect the e^+, e^- (electrons for short) and γ-rays, but the time response is slow due to the ion collection process and won't allow fast losses to be measured. The units used in the VUV ring [2] give integrated dose rates in mR/hr with a readout rate of ~0.5Hz and were easily brought online.

SD's can give faster signals with response times down to nanoseconds if an organic scintillator is used. However, these have less sensitivity for the γ-ray component of the shower. The SD used here are NaI crystals with photomultiplier tube (PMT) [3], since they have high sensitivity for both electrons and γ-rays and have a 250 nsec decay time. This is adequate to see betatron oscillation losses, which have period length of >4 T_o. The $I_s(t)$ signal will directly measure the local charge loss rate during injection or operations. The large signal levels during injection time require the PMT high voltage (HV) to be lowered, to avoid saturation of the output. The time dependence of $I_s(t)$ signal allows detection of betatron and synchrotron frequency loss rates, indicating miss-match of the injected beam into the transverse or longitudinal phase space of the ring or losses from stored beam due to orbit bump miss-match. During normal operations with good lifetime the signal is simply pulses from one-to-few electrons lost per revolution and the pulse count rate (PCR) can be used to measure changes in local loss rate. The HV on the PMT is increased at these times to provide better pulse height detection.

The DD monitor [4] used here has a pair of face-to-face photodiodes in coincidence to detect electrons passing through both detectors. Most γ and X-rays won't make a coincidence in both diodes within the 100nsec pulse time. Since the DD coincidence detects electrons they must be

skramer@bnl.gov
* Work supported by U.S. DOE, Contract No.DE-AC02-98CH10886

mounted close to the beam pipe in order to have large ratio of e/γ ratio, otherwise a high singles rate from γ or X-rays will provide an accidental pulse rate that could exceed the electron rate. They are useful for stored beam operation but may saturate in the higher peak losses during injection.

VUV RING RADIATION MONITORS

The BLM's in the VUV ring are shown in Fig. 1.There are 3-IC (uradm1, 2, and 3) which are located behind thick local shielding in the injection straight section and the following two straight sections. They have been operational since 1988 and have been used to look at changes in the pattern of beam losses. Several times they have verified that a slow vacuum leak was developing from user bellow failure, by showing an increase in local radiation levels versus current over several days. During injection they measure the higher local loss, especially at the injection septum, but this is only qualitative since they saturate in the high peak radiation flux from the injected beam.

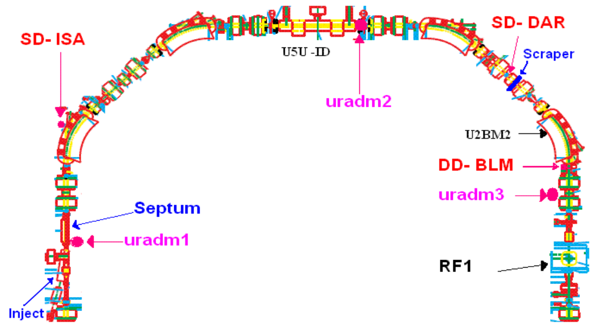

Figure 1: One half of the VUV ring, after the injection septum showing the magnets and BLM's.

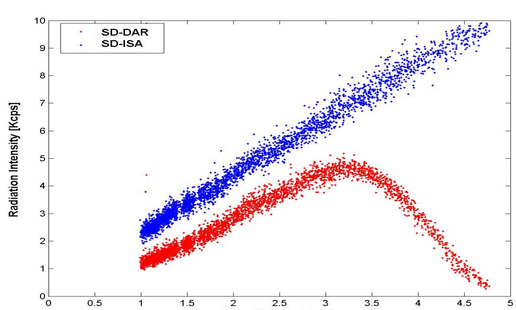

Figure 2: The PCR versus beam loss rate (I_o/τ) of the VUV ring for the two SD's during several operational fills.

The 2-SD monitors have been online since 1996 and are used to measure local loss rate during operations coming from the Injection Septum Aperture, (ISA) the major loss point for Touschek scatters in the dispersion regions [5] and in the Dispersion Aperture Region (DAR), near the beam scrapers. The ISA detector isn't close to the septum, due to the massive shielding, but has a hole in the shield to allow HEBR to pass unattenuated to this SD, which is heavily shielded from the closer back scattered radiation. Figure 2 shows the PCR at these locations as a function of beam current during normal operations. The loss at the ISA essentially scales with the current loss rate, (I_o/τ), however the DAR loss starts low and increases as the beam current drops to ~800 mA where it peaks. The reason for this behaviour isn't fully understood but the rate usually peaks at a current where the RF cavity tuner starts to move to compensate for beam loading.

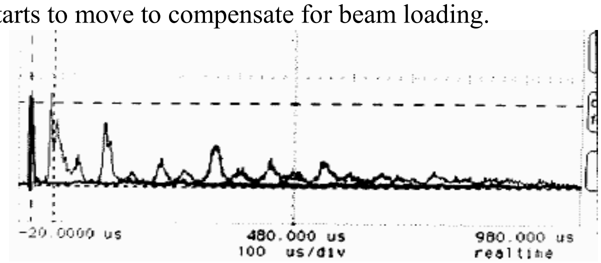

Figure 3: SD-ISA detector beam loss signal during injection from 1998 (full scale 1msec).

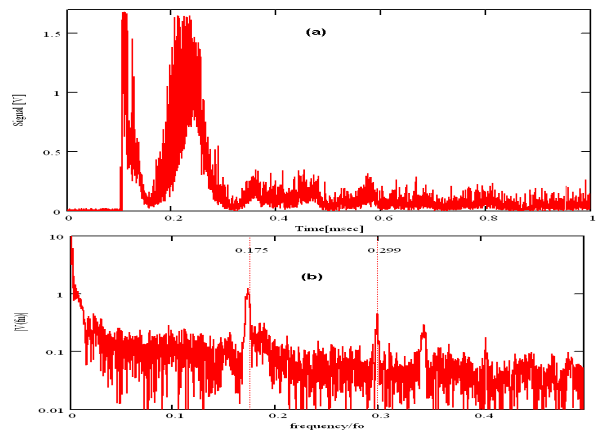

Figure 4: (a) SD-ISA injection loss signal vs time (1msec FS) in 2006 and (b) FFT of the signal in (a) scaled by f_o.

The SD monitors have been most useful for injection optimization. The ISA injection loss observed in 1998 is shown in Fig. 3 where large oscillations at the 11 KHz synchrotron frequency rate are observed for up to 1msec after the injection pulse. This was improved by injection pulse timing between the booster and VUV ring and by lowering the VUV ring energy by 1.1% to better match the booster energy. Figure 4(a) show the injection loss in 2006, which shows two large pulses separated by the synchrotron period, but then much smaller repeat signals. The FFT of this signal is shown in Fig. 4(b) which shows clear signals near the X and Y betatron frequencies. In 2007 it was observed from the beam response that a systematic focusing term was coming from the SF sextupoles, indicating a momentum offset of the closed orbit. After lowering the RF frequency the two large radiation pulses separated by 100μsec have disappeared and only one large peak around the injected beam pulse is seen with a decay signal over a 10μsec, as shown in Fig. 5. The large pulse actually shows the three distinct pulses when operating in one stored bunch mode, the injected bunch (middle pulse) separated by two pulses $\pm T_o$ from the injection bunch, Fig. 5 inset. The amplitude of any residual betatron oscillation signal was reduced using this multi-turn beam bump.

The DD monitor hasn't proved useful for normal operations, since with local shielding reduces the e-signal and increases the γ-ray signal. This detector was used to measure the energy degraded electrons hitting the scraper during scraper studies. The thin (~35% X_{rad}) scraper absorbs energy from the electrons hitting while creating only a small shower off the scraper.

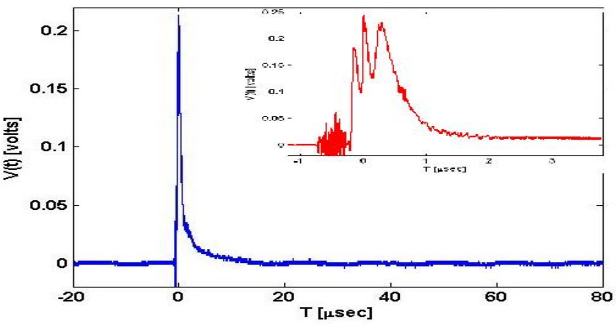

Figure 5: Present SD-ISA injection loss signal vs. time after momentum offset correction. Inset shows details of the pulse (stored and injected beam) during the 3 turn bump.

The lower energy electrons are over bent by the next dipole hitting the inner edge of the beam pipe either inside the dipole (~85%) or as they exit the dipole (~15%). The DD detector is placed against the beam pipe after the dipole and its PCR is shown in Fig. 6 as the scraper position (momentum aperture) is changed. As the aperture is reduced from the beam pipe aperture to the RF bucket height (~1.4%) the DD signal starts to increase as the ISA signal is reduced. This shows the scraper intersecting the Touschek scattered particles that would eventually hit the ISA aperture [5]. Little change is noted in the SD-DAR.

XRAY RING RADIATION MONITORS

With the success of the VUV SD's at understanding injection losses, a set of 4-SD's have been installed in the X-ray tunnel at the upstream end of four dipoles in the injection region. These are mounted about 4" above the beam pipe and are shielded with ~9mm of Pb (due to higher critical energy of the synchrotron radiation) and with 3mm of iron pipe (due to the closeness to the dipole field). The signal cables are run outside the tunnel for measurement with oscilloscope and possibly later to count rate meters. The HV is in common to all units and outside the tunnel for easy changing between injection and stored beam levels. The first two SD's (C1, C2) are upstream of the first two dipoles after the injection septum. With the septum off 100% of the injected beam is lost ahead of C1or slightly after the first dipole. When the septum is turned on injected beam will circulate the ring up to 4-5 turns (2.2-2.8μsec.) before striking the septum. However subtracting the normalized septum off loss signal from the septum on signal, Fig. 7 shows that the loss appears to be in next straight section (RF and X9 IVUN), where SD's C3 and C4 are located, but about one to two turns after the injection pulse enters the ring. Turning on the bump magnet (just ahead of C2) will reduce this loss and betatron loss signals will appear with a 5 turn repeat pattern due to betatron losses. However, these SD's have a much longer decay time than the 250nsec of the VUV ring SD's, making subsequent low level losses harder to detect.

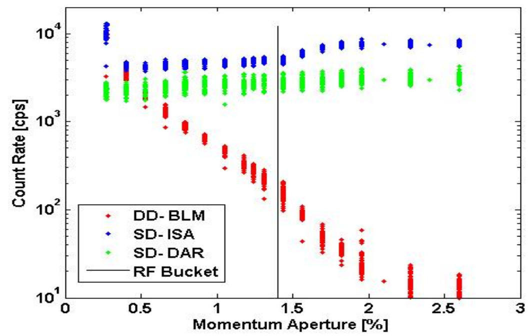

Figure 6: DD, ISA and DAR PCR's shown as the horizontal scraper reduces the ring momentum aperture.

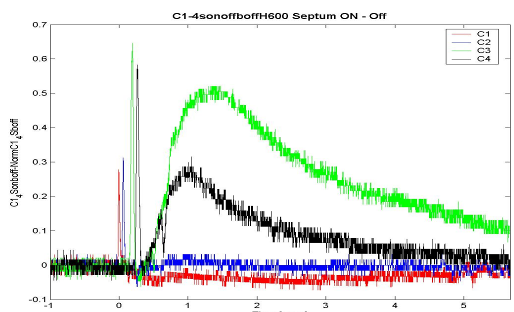

Figure 7: SD signals in the Xray injection period (C1, C2) compared to next period (C3, C4) for the septum on minus the septum off condition.

CONCLUSIONS

The VUV ring has had BLM's installed since 1988 but the installation of SD's has made significant improvements in understanding the injection process and its losses. They have shown the losses from energy, timing and RF frequency mismatches of the injected beam and how improvements in injection efficiency can be made. The SD's installed in the Xray ring have already shown differences in the injection model for the ring, to be studied.

REFERENCES

[1] http://www.nsls.bnl.gov/facility/machine/parameters/
[2] Health Physics Inst., Remote Area Monitor.
[3] ORTEC 2" NaI PMT detector Mod. 905-3.
[4] Bergoz BLM, bergoz.com/products/BLM/BLM.html.
[5] L. Yang, et al., proceedings PAC07, p.1203 (2007).