The Effectiveness of Thin Low-Z Scrapers in Electron Storage Rings

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Abstract

Brookhaven National Laboratory is in the process of constructing a new Electron Synchrotron for scientific research using synchrotron radiation. This facility, called National Synchrotron Light Source II (NSLS-II) [1], will provide x-ray radiation of ultra high brightness and exceptional spatial and energy resolution. It will also provide advanced insertion devices, optics and detectors designed to maximize the scientific output of the facility. The project scope includes the design, construction, installation, and commissioning of the following accelerators: a 200 MeV linac, a booster accelerator operating from 200 MeV to 3.0 GeV, the storage ring which stores 500 mA current of electrons at an energy of 3.0 GeV and 56 beamlines for experiments. It is planned to operate the facility primarily in a top-off mode, thereby maintaining the maximum variation in stored beam current to < 1%.

The NSLS-II with high stored beam energy operation and top-off injection, makes the radiation protection a critical issue.The radiation shield wall of the tunnel is designed to for a loss of 1.1 nC/min of charge, at any one location around the ring. The injection region is shielded for an injection and stored beam loss of 13 nC/min. This thinner shielding around the ring is a concern should the beam develop high current instabilities at locations other than the heavily shielded injection region, that would cause the beam to dump or develop a very short life time. A method has been proposed to control the location of losses by the installation of thin low-Z scrapers in the better shielded injection region. This is to control beam loss without significant deterioration in the stored beam life time and shield effectiveness. This paper presents the results of FLUKA [2] simulation and test measurements to study the effect of thin low-Z scrapers in the storage ring of NSLS-II. Test measurements are conducted at NSLS-I storage ring to study this effect.

1. Use of Scrapers in the Electron Storage Rings

Scrapers in the electron storage rings of third generation synchrotron radiation sources serve two important purposes. They are utilized to provide protection for insertion devices and other storage ring components, minimizing the beam hallow of the injected beam. They define the momentum aperture for the beam for optimum Touschek life time. Scarpers also provide a location for the controlled beam dumps in self shielded diploes for intentional or un-intentional RF and interlock dumps. NSLS-II has planned vertical and horizontal beam scrapers within the heavily shielded injection region with possible additional supplementary shielding if necessary. Comparison study has been made between a low-Z element like copper with a high-Z element like tungsten for the effectiveness of the scraper. The radiological dose impact on the experimental floor as a function of the thickness of the scraper is also evaluated by simulation and measurements.

2. FLUKA Simulations for Scraper Effectiveness

Two scraper configurations are simulated with FLUKA Monte Carlo simulation program. Fig.1 gives the geometry used for FLUKA simulations.

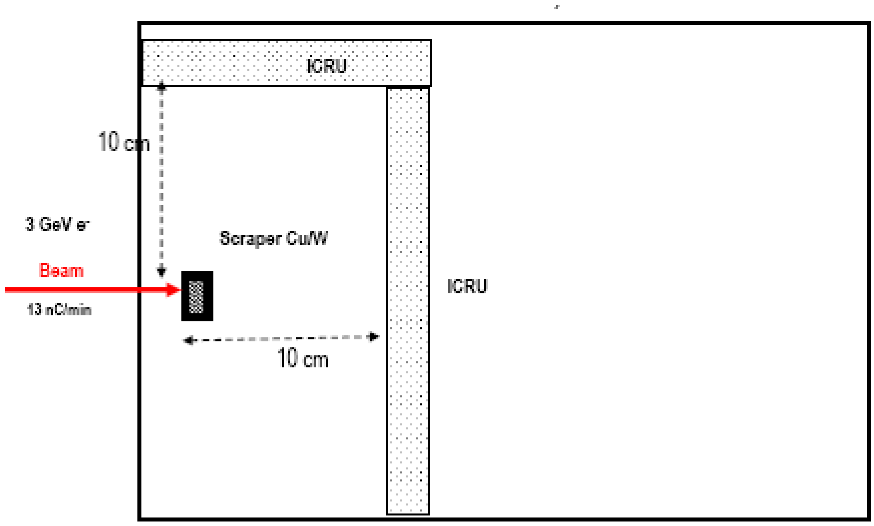


Fig.1 - Geometry used for FLUKA Simulation.

Copper, with good thermal properties, is chosen as the low-Z element and Tungsten as the high-Z element. The copper scraper simulated was 14 mm thick and 20 mm in diameter. The thickness of copper configuration is approximately 1 radiation length (X_0). This is considered to be thin in terms of radiation lengths. The thickness of tungsten is 20 mm, which is approximately 5 radiation lengths of tungsten, a relatively thick scraper. In both cases the transverse and forward scattered dose rates are scored in the ICRU tissue. In addition to, the angular and energy profiles of the scattered electrons emerging after interacting with the scraper are scored by FLUKA.

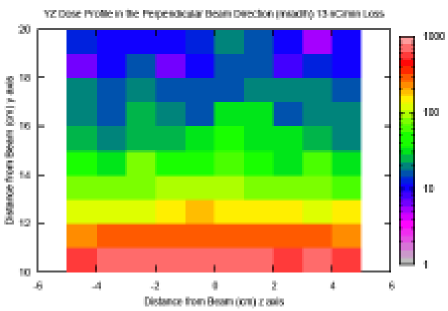


Fig.2a - with Cu Scraper

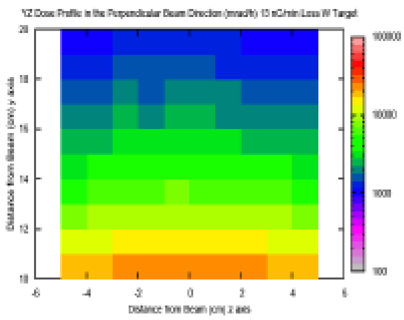
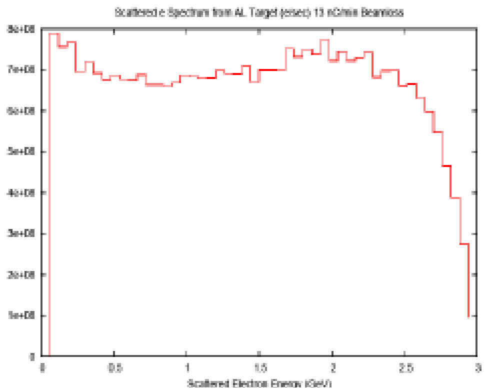


Fig.2b - with W Scraper

Transverse Dose Rate at 10 cm from the Cu and W Scrapers.

Fig.2 a and b gives the transverse directed dose at a distance of 10 cm from the scraper for 14 mm thick copper and 20 mm thick tungsten. The dose rate is scored in terms of mrad/h for a beam interaction rate of 13 nC/min. It can be seen that the dose rate due to transverse scattered electrons and photons from the thin copper scraper is two orders of magnitude lesser than that of the thick tungsten scraper. This is clearly an advantage from the point of radiation safety on the experimental floor. No additional supplementary shielding is necessary for a thin copper scraper in the beam.

The emerging electron energy distribution from a thin copper and a thick tungsten scraper are also investigated. Fig.3a and b provide the electron spectra emerging from the scraper in both cases after interaction.



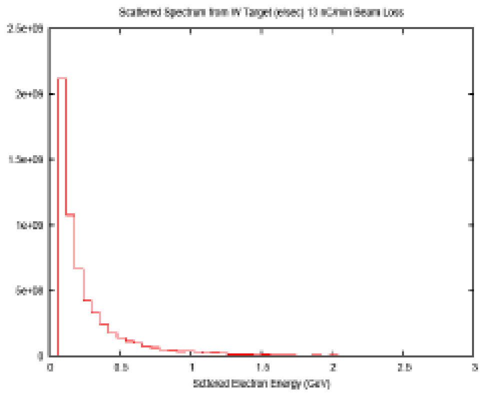
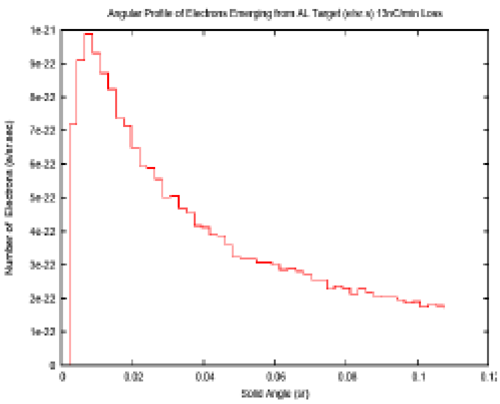


Fig.3a - Cu Scraper *Fig.3b - W Scraper*

The Emerging Electron Energy Distribution from Cu and W Scrapers.

It can be seen that in the case of the copper scraper, the emerging electrons have a wide energy distribution from 0-3.0 GeV. The $1X_0$ copper scraper is not slowing down the electrons as much as the $5X_0$ tungsten scarper. Large number of electrons lost only a small fraction of their initial energy, after interacting with $1X_0$ thick copper, where as almost all of the electrons interacted with $5X_0$ tungsten lost the entire energy. The hope is that the electrons which lost only the fraction of the energy can follow the orbit and dump at the next dipole, which is self shielded. More simulations are required to prove this effect. The tungsten scraper slows down most of the electrons locally creating transverse scattering and higher radiation fields around the scraper, which is illustrated in Fig. 4a and b.



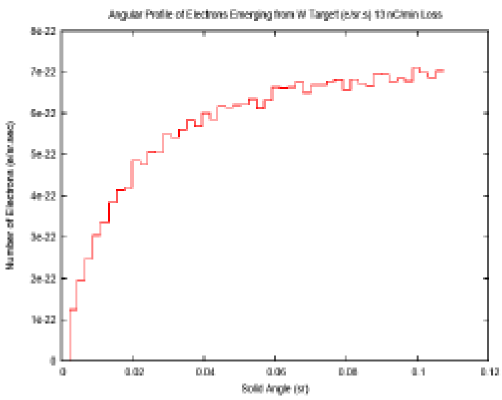


Fig.4a - Cu Scraper *Fig.4b - W Scraper*

Angular Scattering Profile of Emerging Electrons.

Fig.4a and b gives the angular scattering profiles of the emerging electrons from the copper and tungsten scrapers as the function of solid angle, per steradian. The beam direction (0 steradian) is the origin. After interacting with $1X_0$ copper scraper, the electrons have considerable forward momentum, whereas interaction with $5X_0$ tungsten scatterer create wide angle scattering of electrons. This causes high transverse radiation dose rates locally around the scraper.

3. Test Measurements at NSLS Storage Ring

The results of the FLUKA simulation are verified with test measurements at the NSLS storage ring. 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 a radiation shield tunnel, requiring careful understanding and reduction of the radiation losses. The X-ray 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. As 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 BLMs include ionization chambers (IC), scintillation detectors (SD) and more recently diode detectors (DD).

A copper horizontal scraper of 7.5 mm thick was installed in the VUV ring of the NSLS for the purpose of testing the results of FLUKA simulations. Several radiation monitors were employed to detect the beam scraping by the scraper as a function of scraper location. 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 the scraper. The beam life time was also monitored as a function of scraper position with respect to the beam orbit.

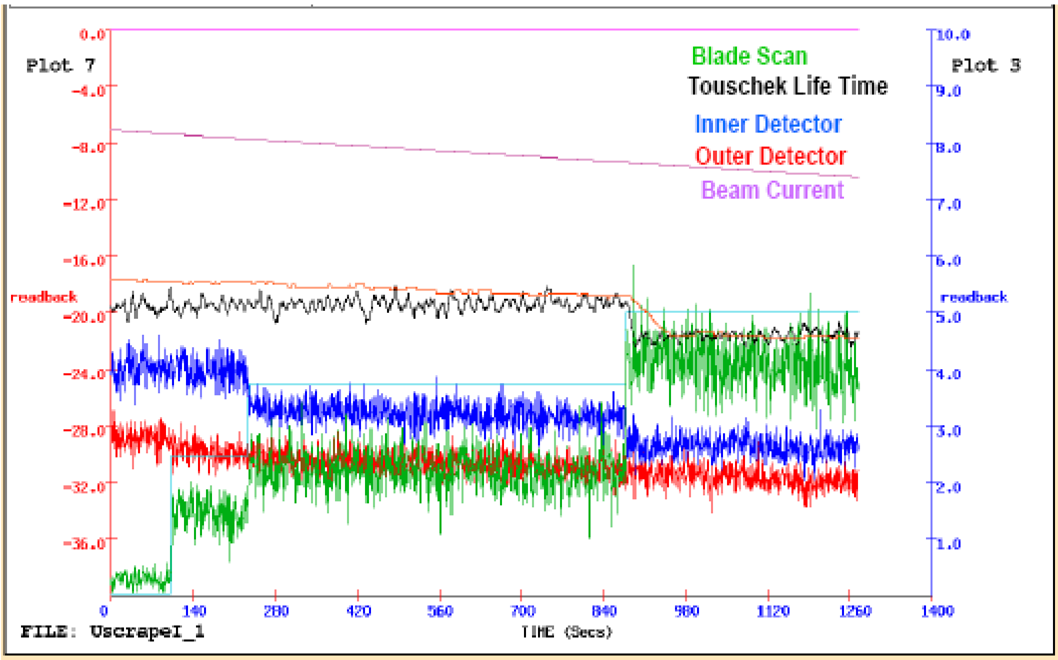


Fig.5 - Results of the Scraper Test Measurements at NSLS.

Fig.5 gives the results of the scraper test measurements at NSLS VUV ring. The installed horizontal scraper was of 7.5 mm thick copper. Its horizontal position with respect to the beam orbit can be controlled and read by an encoder. The plot shows the relative position of scraper with respect to the beam orbit. The plot also shows the corresponding Touschek life time of the beam. Two radiation detectors, one at the inboard and one at the outboard side of the beam orbit, were continuously monitoring the scattered electrons and photons as the scraper blade scan proceeded. The beam current was also monitored.

It was observed that as the scraper position was scanned, inserting it towards the beam orbit, the Touschek life time remained constant until a threshold position was reached. Beyond this threshold location, the scraper was cutting into the core of the beam, causing a decrease in the touschek life time. Both inner and outer orbit radiation detectors showed slight decrease in scattered radiation as the scraper was inserted towards the beam orbit, signaling a reduction in the scattered radiation due to beam interactions with the scraper. We conclude that this effect is due to electrons, which loose a fraction of their forward momentum due to interactions with scraper, tend to bend towards inward of the orbit to be stopped by the self shielded dipoles in the ring. The dipole yoke act as an effective beam dump absorbing the radiation. This causes a reduction in the radiation environment detected by the inner and outer Beam Loss Monitors.

4. Summary and Conclusions

Low-Z thin scrapers of less than one radiation length of thickness have several advantages over the high-Z thick scrapers. Most importantly they do not require additional local supplementary shielding inside or outside the storage ring. The small energy loss of the electrons due to interactions with the thin copper scraper render them mostly in the forward direction and eventually get them dumped in the next dipole magnet in the ring. This causes low photon radiation exposure outside the storage ring shield wall with reduced transverse scattering of electrons and photons. Low-Z elements like copper, silicon etc. have low photoneutron production per primary electron resulting low neutron dose outside the storage ring shield wall. This effect must be verified by additional investigations.

Additional measurements are planned at the NSLS storage ring to further verify some of the observations of this paper

References

[1] National Synchrotron Light Source II Project, Preliminary Design Report, November 2007.
[2] FLUKA, A Multi-particle Transport Code, CERN Report 2005-010 (2005).
[3] National Synchrotron Light Source, Safety Assessment Document, BNL 49214-Rev002, March 1996.