BROOKHAVEN NATIONAL LABORATORY

BNL-73569-2005-CP

Electron Cloud at Collimator and Injection Region of the Spallation Neutron Source Accumulator Ring

L. Wang, et. al.

To be presented at Particle Accelerator Conference
Knoxville, Tennessee
May 16-20,2005

Collider-Accelerator Department

Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000
www.bnl.gov

Managed by
Brookhaven Science Associates, LLC
for the United States Department of Energy under
Contract No. DE-AC02-98CH10886

DISCLAIMER

ELECTRON CLOUD AT COLLIMATOR *AND* INJECTION REGION OF THE SPALLATION NEUTRON SOURCE ACCUMULATOR RING*

L. Wang, H. Hseuh, Y.Y. Lee, D. Raparia and J. Wei, BNL, UPTON, NY, **USA**
S. Cousineau and S. Henderson, ORNL, Oak Ridge, TN, USA

Abstract

The beam loss along the Spallation Neutron Source's accumulator ring is mainly located at the collimator region and injection region. This paper studied the electron cloud build-up at these two regions with the three-dimension program CLOUDLAND.

1 INTRODUCTION

Spallation Neutron Source (SNS) is the most powerful pulsed neutron source under construction with a repetition rate of 60Hz that accelerates proton beam up to 1GeV with 1MW initial beam power that is to be upgraded to 2MW. Hands-on maintenance requires that uncontrolled beam loss should be less than 1 nA/m at 1GeV energy, which corresponds to 10^{-6} of 1MW beam power per meter. Three collimators are installed to absorb halo particles and contain activation due to secondary particles in order to meet the beam loss requirement. A strong electron cloud may build-up due to the large beam loss at the collimator region. The collection of stripped electron at the injection region is another main concern about the electron cloud. This paper explores the electron cloud at these two regions with the 3D PIC program CLOUDLAND [1].

2 ECLOUD AT COLLIMATOR REGION

Figure 1 shows the simulated power deposition due to controlled losses on the collimators and uncontrolled beam loss on the beam pipe, magnets, etc. The simulation with ORBIT shows that the beam loss is mainly located at the three collimator-regions. The peak power deposition at the three collimators is 500, 350 and 240 W/m, respectively. Figure 2 shows the aperture of the beam pipe and beam size at the collimator region. The aperture of the secondary collimators is lager than the primary one to avoid the direct interception of halo particles. However, the aperture in the three collimators is smaller than that in the regular region, which is typically 100 *mm*. This difference in pipe aperture makes the electron cloud have different feature as shown later.

A major unknown factor is the proton-electron yield. This yield depends on the incident angle, material and particle energy [2-3]. Figure 3 shows the distribution of the loss particles at the secondary collimator. The loss particles have large incident angle. Therefore, a larger proton-electron yield is expected there. A proton-electron yield of 100 is assumed in the simulation,of electron cloud inside the collimators. Major part of electrons is lost on the front end of the collimator, where the incident angle is expected to be small. Hence, a small proton-electron yield of 1 is used there.

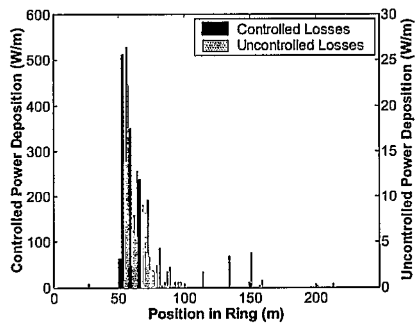

FIG. 1 Power deposition along the ring

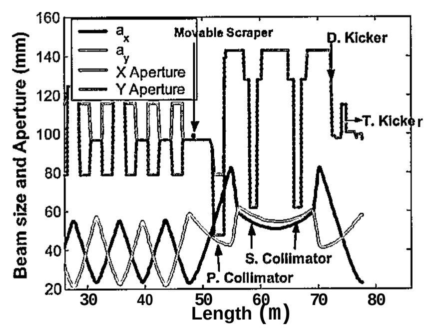

Figure 2 Beam pipe aperture and beam size at the collimator region

First, we assumed that all particles lost inside the collimators with a proton-electron yield of 100. Figure 4 shows that the electron cloud build-up in the three collimators. The electron cloud at the secondary collimator has the maximum density although there is more beam loss in the first collimator. The mechanism is that the electron's energy gain in the first collimator is smaller due to the smaller aperture of beam pipe there. In principle, the energy-gain increases linearly with pipe radius [4]. The energy-gain is less than 100 *eV* inside the collimators. Therefore, there is no multipacting during the beam passage except the very short period at the bunch tail. Benefiting from the small pipe aperture, the electron cloud is not a serious problem inside the collimators even with the assumption that all beam loss inside the collimator and a larger proton-electron yield.

*Work performed under the auspices of the U.S. Department of Energy. SNS is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy. **SNS** is a partnership of six national laboratories: Argonne, Brookhaven, Jefferson, Lawrence Berkeley, Los Alamos, and Oak Ridge.

For the particles lost outside the collimator, electron multipacting will be important due to the high energy-gain. The realistic model needs the detail of the proton loss position and incident angle.. For lack of this information, we assume that all particles hit the surface with radius of 100 mm with a small proton-electron yield of 1. Although a smaller proton-electron yield is used here, the electron cloud is close to the level of that inside collimator (with small pipe aperture) as shown in FIG. 5. **A** strong multipacting is expected outside of the collimators. Therefore, the electron cloud in front of the collimator is significantly sensitive to the detail of the proton loss: the location and incident angle. More realistic study needs to model the detail beam loss process.

If the number of electron in the segment between the collimators is sizeable, a weak solenoid field can be applied to suppress the electron cloud there. Simulation shows that a 30G field is enough to suppress the electron cloud.

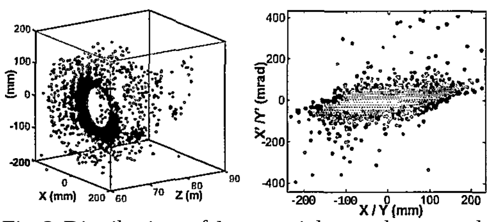

Fig **3** Distribution of loss particles at the secondary collimator

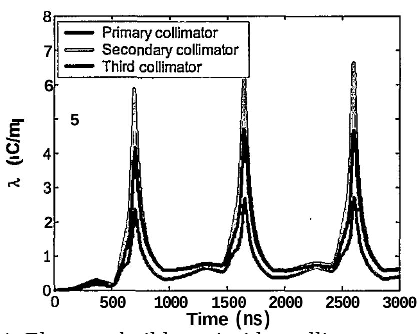

Figure 4 Electron build-up inside collimators with a proton-electron yield of 100.

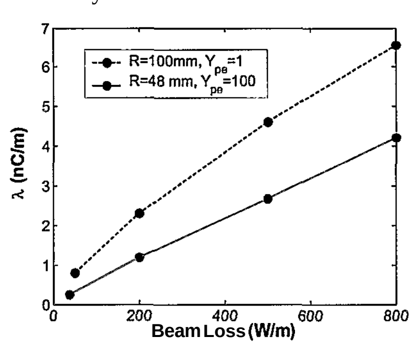

Figure **5** Effects of pipe aperture for different beam loss

3 ECLOUD AT INJECTION REGION

The electrons are stripped from an injected H- beam generated by the Linac when H- beam hits a carbon foil, which locates in the gap of a dipole magnet with a field of $0.25T$ at the foil center. With an H^- beam, the stripped electrons carry twice the current of the injected H- beam with a kinetic energy of 525 keV. The stripped electrons are guided by the magnetic field and collected by a water-cooled device of heat-resistant material, the electron catcher that is located at the bottom of the chamber. Figure 6 illustrates mechanism of collecting stripped electrons at the SNS's Ring.

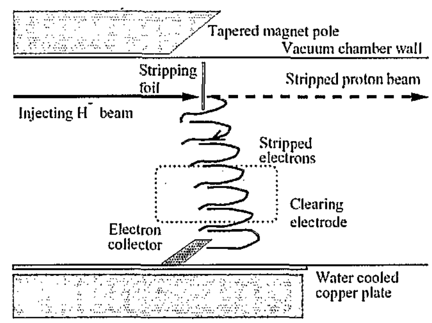

Figure 6 Collection of stripped electrons during the injection of the H- beam at the SNS ring. The foil is place in a dipole magnet, which is part of the injection bump. The low pole surface of the magnet is extended downstream by about 20 cm so that the electrons are guided down to the electron collector.

The catcher has a serrated shape with slightly overhanging surface. The real catcher consists of 4 pieces of the pyramids so that the electrons that miss one pyramid can hit the next one. If a stripped electron hits the catcher's top surface, the secondaries and backscattered electrons tend to rebound upward and return the beam's chamber. To reduce this probability, the catcher's position and geometry must be optimized so that the stripped electrons hit its front surface [5]. The secondaries have only a few eV of energy and will, therefore, spiral tightly about the local magnetic-field line. The catcher's overhanging surface then will prevent them from reentering the vacuum space. On the other hand, the overhanging surface cannot completely prevent backscattered electrons from escaping into the attractive potential of the circulating beam because of their high energy and hence, big radius of gyration. However, the catcher's structure ensures that the electrons hit it several times before they can reenter the beam's chamber. The yield of backscattered electrons is smaller than unity, and most of them die out due to the reduction in their chances of reflection caused by their hitting the catcher's surface multiple times.

Generally, the backscattered electron coefficient, η increases with increasing atomic number. Figure **7** shows the backscattered electron coefficient of carbon, stainless steel, and copper with normal incidence electrons [6]. The backscattered electron yield of carbon is about one order-of-magnitude smaller that of copper at the energy of 525keV. Copper was chosen at the original design and carbon is finally used to reduce the reflected electrons. Carbon also has lower yield of secondary electrons than copper. Therefore, using a carbon catcher is preferable considering both secondaries and backscattered electrons.

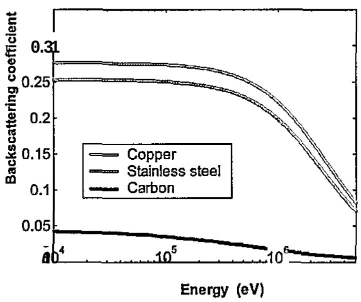

Fig. 7 Backscattered electron coefficient of carbon, stainless steel, and copper with normal incidence electrons

The stripped electrons take about 1.7 *ns* to reach the catcher. With a carbon catcher, the electrons inside the beam's chamber saturate quickly within 1.7 *ns* because only 0.34% of them can reenter the chamber. On the other hand, with a copper catcher 9.2% stripped electrons could reenter it. The distribution of the electron cloud with a carbon and a copper catcher are shown in Fig 8. Electrons undergo about five periods of gyration before they reach the catcher. The reflected electrons are clearly shown in the case if a copper catcher, but not for carbon due to its slow rate of accumulation.

To check the effect of the catcher's serrated surface on the build-up of the electron cloud, we simulated the case of a carbon catcher with smooth flat surface parallelizing beam direction. It is found that about 12% of the electrons can reenter beam's chamber. Therefore, the serrated surface pays an important role on reducing the numbers of reflected electrons due to the multi-scattering inside the serrated structure.

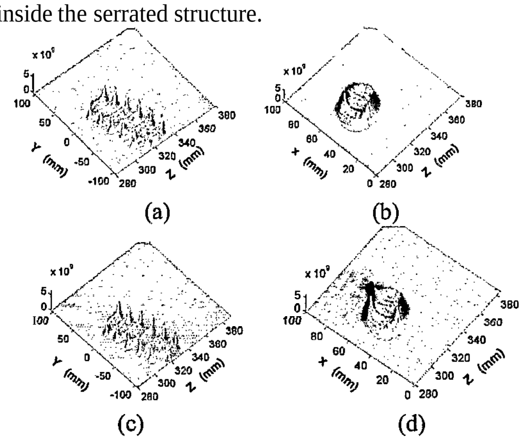

Figure 8 Distributions of electron cloud with a carbon (a)(b) and copper (c)(d) catcher.

The Secondary electrons induced by the impacting of the injection- and circulating-beams have a low emission energy (tens of eV), and hence, they will circulate around the magnetic field lines with small radius less than 0.1 mm. Unlike the stripped electrons, the secondaries may go up or down along the magnetic-field lines. They will be vertically trapped by the circulating beam and move downstream longitudinally due to the cross-field drift

$$v = \frac{\mathbf{E}\times\mathbf{B}}{B^2}. \qquad (6)$$

where E is beam's field. The electrons are released at the bunch tail. They move up or down along the magnetic field lines and hit the surface of the pipe during the bunch gap. Figure 9 shows a sample of the electrons's orbit. An electron can move downstream up to 0.2 in during one bunch's passage. As a result, the lost electrons at the pipe's surface form a longitudinal strip with a horizontal position at the foil's center. These electrons do not exhibit multipacting due to their low energy gain and trapping.

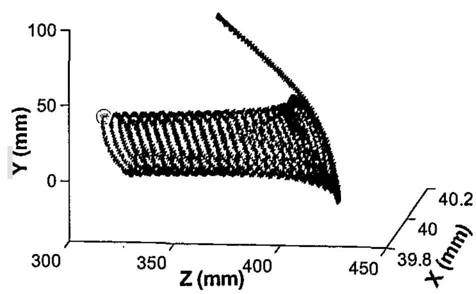

Figure 9 The orbit of a trapped electron. The electron is emitted from the foil at the peak of the beam's profile. It hits the beam's pipe at the bunch tail. The red dot is its emission position, the circulating-beam is in +Z direction.

4 CONCLUSION

The electron cloud in the collimator region is estimated with a simple model of the beam loss. Simulation shows the electron cloud inside the collimator is not a serious problem due to the lack of electron multipacting. Instead, more electrons may accumulate near the front end of the collimators where there is significant beam loss and strong multipacting. A carbon catcher can collect 99% stripped electrons with an optimised position and geometry.

5 REFERENCES

[1] L. F. Wang, et.al., Phys. Rev. ST-AB, 5, 124402,2002
[2] O. Grpbner, LHC Project Report, 127(1997)
[3] Zhang *S.Y.*, Proceedings of the 1999 Particle Accelerator Conference, New York, 1999
[4]L. Wang, et. al., Phys. Rev. E, V70, 036501(2004).
[5]Y.Y. Lee, et. al., This Proceedings.
[6]T. Tabata, R. Ito and S. Okabe, Nuclear instruments and methods 94, 509-513(1971)