ELECTRON CLOUD IN THE COLLIMATOR- AND INJECTION- REGION OF THE SPALLATION NEUTRON SOURCE'S ACCUMULATOR RING*

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Abstract

Beam loss along the Spallation Neutron Source's accumulator ring is mainly located at the collimator region and injection region. This paper discusses the electron cloud build-up, control and collection at these two regions simulated with the three-dimension program CLOUDLAND.

INTRODUCTION

The Spallation Neutron Source (SNS) is the most powerful pulsed-neutron source under construction. It has a repetition rate of 60Hz that accelerates a proton beam up to 1GeV with 1MW initial beam power, which is to be upgraded to 2MW. Hands-on maintenance requires that the 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 were installed to absorb halo particles and contain activation from secondary particles to meet this requirement on beam loss. A strong electron cloud may build-up due to the large beam loss at the collimator region. Collecting stripped electrons 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].

ECLOUD AT THE COLLIMATOR REGION

Figure 1 depicts the simulated deposition of power due to controlled losses on the collimators, and to uncontrolled beam loss on the beam pipe, magnets, and the like. Simulation with ORBIT reveals 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's pipe and the beam's size at the collimator region. The aperture of the secondary collimators is larger than that of the primary one to avoid directly intercepting 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 the pipes' aperture results in the electron cloud having different features, as described later.

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

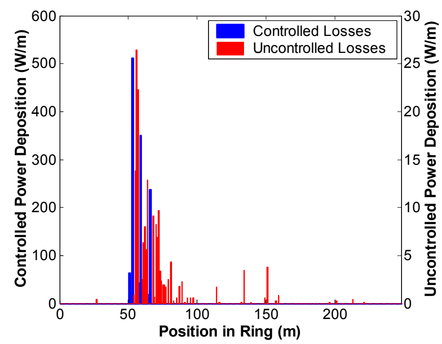

Figure 1: Power deposition along the ring.

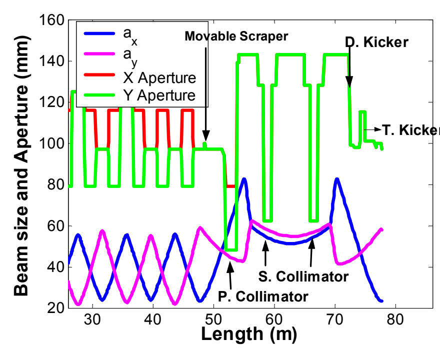

Figure 2: Beam pipe' aperture and beam size at the collimator region.

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

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For particles lost outside the collimator, electron multipacting will be important due to their high energy-gain. A realistic model needs to detail the position of proton loss and the incident angle. Lacking 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 small proton-electron yield is used here, the electron cloud is close to the level of that inside the collimator (with a small pipe aperture) as shown in FIG. 5. Strong multipacting is expected outside the collimators. Therefore, the electron cloud in front of the collimator is significantly sensitive to the details of proton loss: the location and incident angle. If the number of electrons in the segment between the collimators is sizeable, application of a weak solenoid field will suppress the electron cloud there. Simulation shows that a 30G field is enough to suppress the electron cloud.

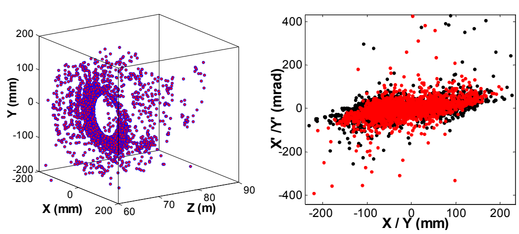

Figure 3: Distribution of lost particles at the secondary collimator.

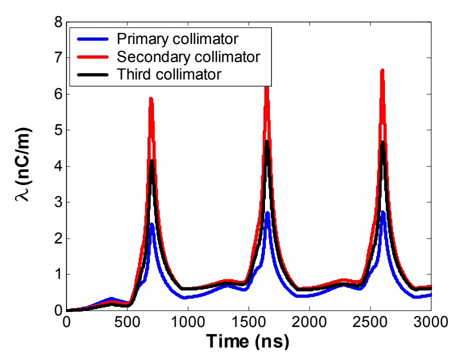

Figure 4: Electron build-up inside the collimators with a proton-electron yield of 100.

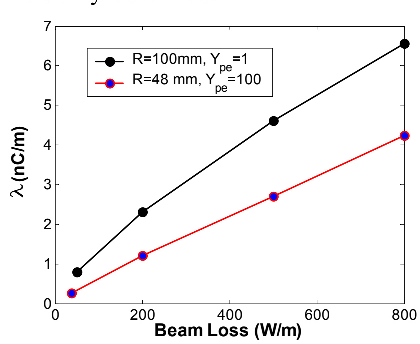

Figure 5: Effects of different pipe apertures on beam loss, R is the radius of beam pipe and Y_{pe} is the proton electron yield.

ECLOUD AT THE INJECTION REGION

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

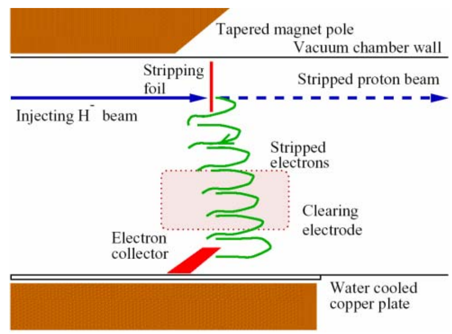

Figure 6: Collection of stripped electrons during the injection of the H- beam at the SNS ring. The foil is placed in a dipole magnet, which is part of the injection bump. The low pole surface of the magnet is extended downstream by about 20 cm so that the electrons are guided down to the electron collector.

The catcher has a serrated shape with slightly overhanging surface. The real catcher is made up of 4 pieces of pyramids, so that any electrons that miss one pyramid 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 re-entering the vacuum space. Nevertheless, the catcher's 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 re-enter the beam's chamber. The yield of backscattered electrons is smaller than unity, and most of them die out as their hitting the catcher's surface multiple times reduces their chances of reflection.

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

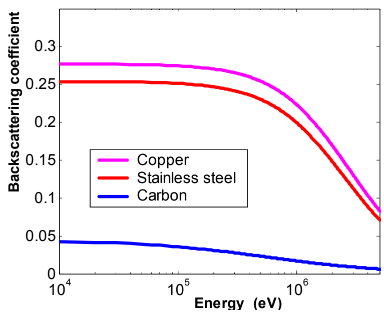

Figure 7: Backscattered electron coefficient of catchers of carbon, stainless steel, and copper with normal incidence electrons.

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. With a copper catcher, 9.2% stripped electrons can do so. Figure 8 illustrates the distribution of the electron cloud with a carbon and a copper catcher. Electrons undergo about five periods of gyration before they reach the catcher. The reflected electrons are clearly shown in the case of the copper catcher, but not for carbon due to their slow rate of accumulation.

To check the effect of the catcher's serrated surface on the build-up of the electron cloud, we simulated a carbon catcher with smooth flat surface paralleling the beam's direction. We 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 multi-scattering inside such a structure.

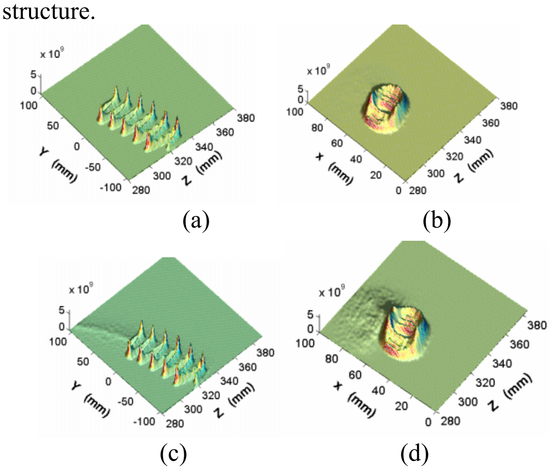

Figure 8: Distributions of electron cloud with a carbon (a)(b), and a copper (c)(d) catcher.

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

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

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

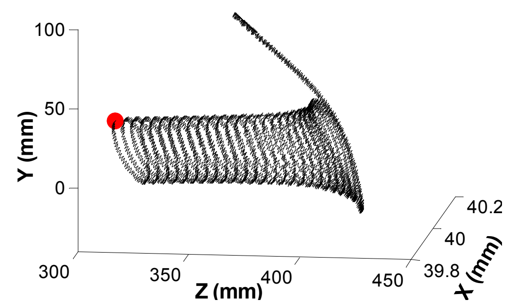

Figure 9: The orbit of a trapped electron. The electron is emitted from the foil at the peak of the beam's profile. It hits the beam's pipe at the bunch tail. The red dot is its emission position, the circulating-beam is in +Z direction.

CONCLUSION

We estimated the electron cloud in the collimator region with a simple model of the beam loss. Simulation shows that 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, with an optimized position and geometry, can collect 99% of the stripped electrons.

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