

SNS RING INJECTION STRIPPED ELECTRON COLLECTION: DESIGN ANALYSIS AND TECHNICAL ISSUES*

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Abstract

This paper describes the simulation studies on the motions of stripped electrons generated in the injection section of the Spallation Neutron Source (SNS) accumulator ring and the effective collection mechanism. Such studies are important for high intensity machines, in order to reduce beam loss and protect other components in the vicinity. The magnetic field is applied to guide electrons to a collector, which is located at the bottom of the beam vacuum chamber. Part of the study results with and without considering the interactions between electrons and materials are presented and discussed. The final engineering design of the electron collector (catcher) is also described.

INTRODUCTION

The electron multi-pacting induced by beam loss and residual gas ionization along the ring has been studied in detail [1]. In the SNS accumulator ring straight section, electrons are stripped from the injected H^- beam through a carbon foil. These protons must make 1100 turns to be compressed from 1 ms Linac pulse into a 700 ns bunch with $2E14$ protons. The stripped electrons will have the same initial velocity but twice the intensity (current) of the H^- beam. In this paper, we report the studies on electrons, and the optimum design of the collector.

GUIDING MAGNETIC FIELD

In the injection straight section, the fixed orbit bump is a chicane consisting of four dipole magnets. The carbon foils are placed in the second chicane dipole magnet, which provides monotonically decreased magnetic field along the vertical direction. The third chicane dipole magnet then provides the compensation on the uniformity of the integrated field. The total integrated field of these four chicane magnets must be zero, which has no effect on the circulated beam. [2] To control the movement of the stripped electrons, the foil is located at the downstream fringe field of the second chicane dipole magnet with coordinates $(x, y, z) = (40, 23, 307)$ mm. Assuming the origin is at the center of this magnet; x is in the outwards radial direction; y is in the vertical direction; and z is in the beam tangential direction.

The fringe field from an ordinary dipole magnet has the

“magnetic bottle” effect, i.e., the field strength is stronger at the top and bottom than that of the middle. The stripped electrons possess 1.4 kW average power. If they are not guided to a safe location, then they could repeatedly move up and down, result in significant beam loss and foil mechanical system damages. To ensure the stripped electrons are not reflected upwards before reaching the electron catcher, the lower pole of the second chicane magnet is extended by 200 mm with respect to the upper pole, so that the flux density at the bottom pole (where catcher is located) will be lower than at the foil. Figure 1 illustrates the mechanism of electron collection from a side view.

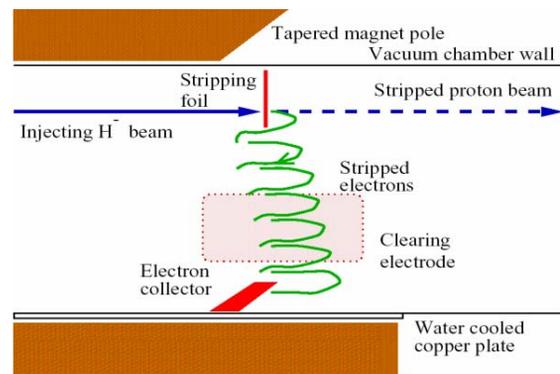


Figure 1: Schematic Mechanism of Electron Collection

OPTIMIZATION OF THE CATCHER

Electron tracking simulations were first performed in the 3d magnetic field created by Opera. [3] The electrons make helical trajectories with a gyration period of 0.29 ns ($2\pi m_0 \gamma v_{\perp} / eB$) and a radius of 12 mm ($\gamma m_0 v_{\perp} / eB$). During this process, the magnetic field induction B as seen by the electrons varies from 2.5 kG (near the foil) down to 2.4 kG (near the bottom of the vacuum chamber). As the electrons descend from the foil, the helical center moves in the longitudinal direction around the magnetic flux lines, towards the downstream. Simulations have shown that the electron landing angles are in the range of 17.6 to 20.5 degree, under the considerations of uncertainties of the electron birth location and momentum. Figure 2 shows a sample of the electron trajectory, which was initiated from $(40, 20, 307)$ mm, in horizontal and vertical planes.

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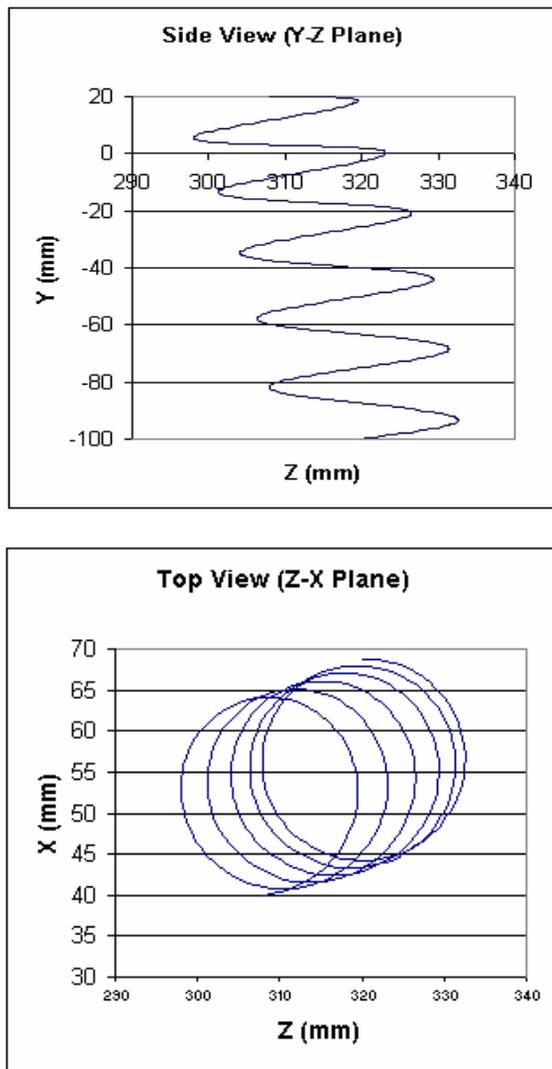


Figure 2: Typical Electron Trajectory

The catcher consists of 5 pieces of serrated shaped “pyramids”. The cross-section of the each piece is shown in Fig. 3. If electrons miss one of those pyramids, the next one can catch them.

However if some electrons hit the top surface of the pyramids, then the secondary and backscattered electrons will tend to rebound upwards and return to the beam chamber. To reduce this probability, further study was

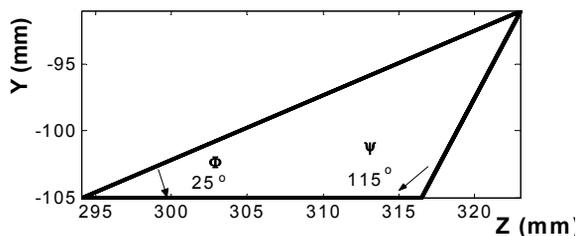


Figure 3: Cross-section of the pyramids

performed on the interactions between the electrons and the catcher surface. A full model was established, which includes the realistic catcher geometry and the 3d field map. Studies have shown that the position of the stripped electrons at the catcher is sensitive to the vertical and longitudinal position of the catcher. In order to confine the secondary electrons and reduce the chances of reflection of back-scattered electrons, the catcher should be located in a suitable position. Figure 4 shows the comparison on the electron distribution if the catcher placed at different vertical locations. The area of the electron distribution is very small: on the order of 5 mm vertically and 2 mm longitudinally.

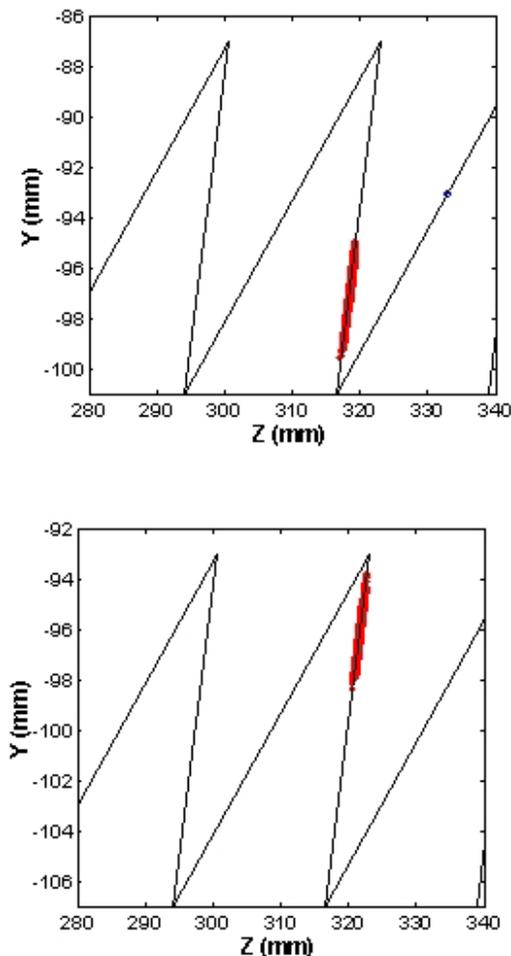


Figure 4: Distributions of stripped electrons on the catcher surface. (In the bottom plot, the catcher is moved 6 mm lower)

Optimization of the vertical position of the catcher is shown in figure 5, which plots the relationship between the location of the catcher and the capture efficiency. It can be seen that the optimized vertical bottom location of the catcher is $Y = -106$ mm.

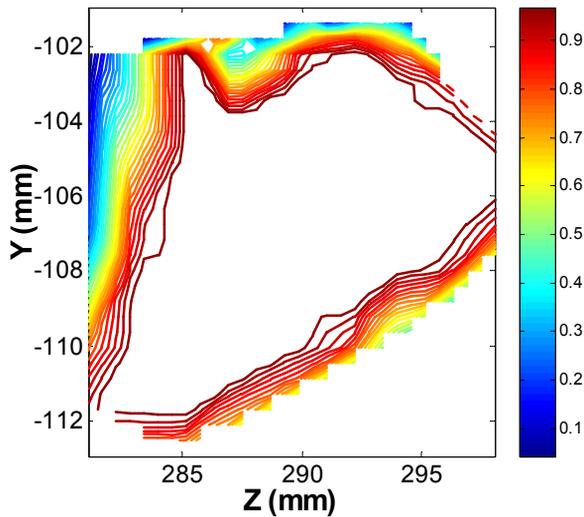


Figure 5: Capture Efficiency vs Catcher Location

During these studies, we also considered the position and momentum errors that H⁺ hits the foil. We have learnt that stripped electrons can be sufficiently collected by using a semi-circular catcher with a radius of 30 mm. The optimum position of the center of this semi-circle (the middle point of its diameter) should be located at x=76 mm, z=290 mm, with the tolerance of ±1.0 mm.

FINAL DESIGN OF THE CATCHER

The catcher consists of five wedge shaped pieces (pyramids) machined from carbon impregnated carbon fiber (carbon-carbon). The machined surface finish on these pieces is on the order of 32 micro-inches. Figure 6

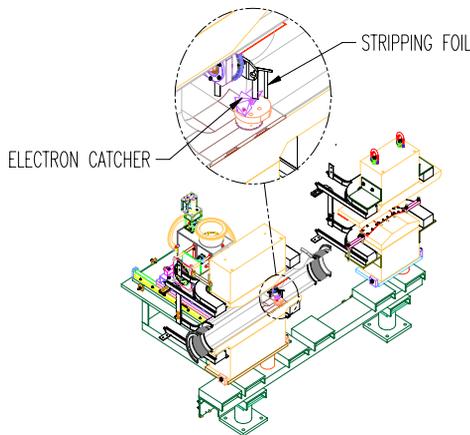


Figure 6: Electron Catcher and Magnet Assembly

shows the perspective drawing, which includes the assembly of the foil mechanical system, the second and the third chicane dipole magnets. The foil and the electron catcher are highlighted in a circle.

A steady state thermal analysis of this finalized catcher design indicates acceptable operating temperatures. The result of this analysis is shown in Figure 7, which plots temperature contours. The maximum temperature seen by the carbon-carbon pyramids is around 730 degree Fahrenheit with an assumed cooling water channel temperature of 150 degree Fahrenheit while the input heat of 2 kW. The water-cooled channel is located below the carbon-carbon wedges, integrally machined into the vacuum chamber.

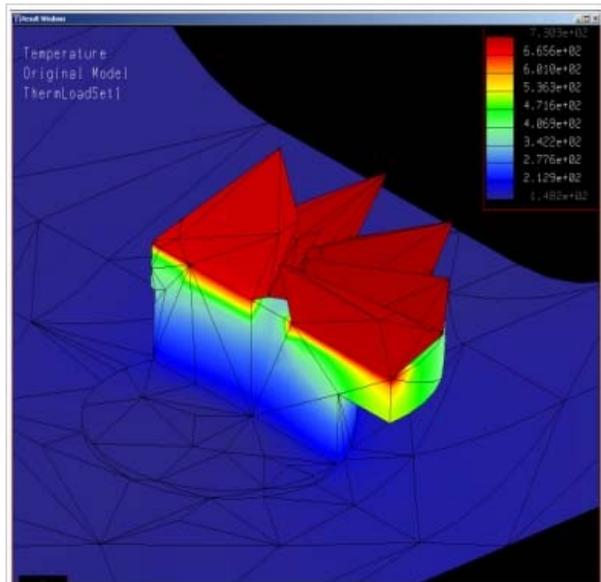


Figure 7: Temperature Contour Plot

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