IMPACT OF UNCAUGHT FOIL-STRIPPED ELECTRONS IN THE SPALLATION NEUTRON SOURCE RING

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Abstract

Evidence of hardware damage in the Spallation Neutron Source ring suggests that a non-negligible fraction of the foil stripped electrons are reflected back into the vacuum chamber. This paper summarizes the results of a 3D computational study that explores the dynamics of the foil-stripped, uncaught electrons.

INTRODUCTION

In high beam power accelerators which utilize H- charge exchange injection, the stripped electron beam must be carefully controlled to minimize the probability of electrons intercepting local hardware. In the 1 GeV, 1.4 MW Spallation neutron source ring [1], an electron catcher was installed for this purpose. The catcher was designed to catch the stripped electrons with very high efficiency [2]. However, due to relocations of the injected beam spot after the start of beam operations, as well as improper positioning of the catcher itself inside the chamber, the catcher is unlikely to have ever achieved the design efficiency. Multiple observations of hardware damage in the injection region suggest that a non-negligible fraction of the electrons are being reflected back into the chamber where they pose a significant threat to the local hardware.

This project was initiated to explore the dynamics of uncaught electrons in the SNS injection region. Only electrons which strike the top surface of the catcher are considered, e.g. those which constitute "catcher in-efficiency". The computational model employed includes electron tracking in the 3D field of the magnet, a surface interaction model for the electrons intercepting the catcher surface, and absorbing apertures to map out the final impact distribution of electrons.

The SNS injection configuration has evolved over time [3]. Two specific operational configurations were simulated in detail in this study, and results were compared with experimental observations. This paper presents only a brief overview the project. A full description can be found in reference [4].

EVIDENCE OF REFLECTED ELECTRONS

Three experimental observations indicate the presence of uncaught, reflected electrons in the SNS injection region. First, black marks have been observed on the top surface of the catcher surface. In the design electron catcher scheme, electrons should intercept the underside of one of five undercut wedges. The fact that there are black marks on the top surface of the catcher indicates that a substantial fraction of the electrons either are not now, or were not at some point during operations, being properly caught.

Second, a ring-shaped black mark has been observed on the top of the vacuum chamber above the stripper foil mechanism. This mark is thought to be caused by reflected electrons impacting the top of the beam pipe.

Third and last, melted metal was observed on the bracket and arm of a 3rd generation foil assembly [3]. The suspected cause was reflected electrons, and modifications were made to the geometry and material of the next generation assembly to alleviate the problem.

ORBIT 3D COMPUTATIONAL MODEL

The ORBIT code is a PIC-style, open-source code developed for simulating high intensity beams [5]. The code contains a module for particle tracking in a 3D magnetic field. This feature was combined with a with Monte-Carlo style surface interaction model to simulate the stripped electrons in the SNS injection chamber. The surface model is based on scattering probability distributions generated by MCNPX for 545 keV electrons impinging on carbon at various incident angles. Only one scattering event is allowed for each electron, and for typical SNS electron incident angles, the MCNPX results indicate that the probability of absorption vs. reflection at the catcher surface is 60/40, respectively. Furthermore, the scattering is primarily elastic and within the plane of incidence, and the in-plane scattering angle is peaked near mirror-reflection.

Finally, hardware in the injection region, such as the top of the vacuum chamber and the foil assembly, were modelled as absorbing apertures.

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SIMULATION RESULTS

The convoy electron dynamics for the present SNS injection configuration, which includes a 4th generation foil assembly, was simulated. The electron distribution was launched at the foil with parameters inherited from the nominal SNS beam for the present 930 MeV H- linac beam energy. Electrons were then tracked until an absorption event occurred.

Significant features of the electron motion include precession about the magnetic field lines with gyroradius ~12mm, centriod motion which follows the field lines downward in y toward the bottom aperture and slightly downstream in z, and finally a positive x drift due to the field gradient. In addition, if an electron is reflected from the bottom surface and begins to travel back upwards, there is a small probability of reflection from the magnetic field pinch effect. Note that all electrons are eventually lost in the simulation, and the final result is an impact distribution of electrons.

The convoy electrons are guided by the B field lines to the bottom aperture by design. At this point, the electrons have some probability of absorption or reflection based on the MCNPX data. If an electron is reflected and re-enters the vacuum chamber, it can intercept the local hardware. Altogether, there are 4 distinct fates for the electrons: 1) absorption on the bottom surface, 2) reflection on the bottom surface followed by absorption on the top surface, 3) reflection on the bottom surface followed by absorption on the foil assembly (foil, bracket mount or bracket arm), and 4) reflection on the bottom surface followed by reflection from the B field and final absorption on the bottom surface.

Figure 1 shows an X-Y view of a typical simulated electron trajectory, in this case for an electron which was reflected from the bottom surface and eventually lost on the top beam pipe aperture. Also shown in the figure is the final impact distribution of the 10,000 incident electrons launched from the foil. The impact distribution shows that a significant amount of electrons intercept the foil assembly, as well as the top and bottom surfaces.

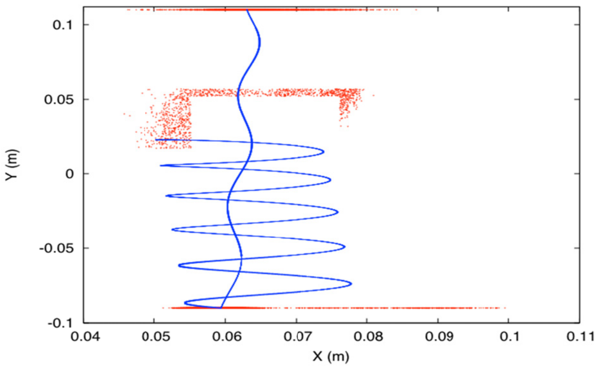

Figure 1: X-Y view of the impact distribution (red points) and an example electron trajectory (blue lines).

Figure 2 shows a 3D view of the impact distribution and the electron trajectory shown in Figure 1. The dense spot located on the bottom surface is due to electrons absorbed on their first interception of the bottom surface, which in this case is the top of the catcher surface. This is the most localized impact spot. Because the initial energy spread of the electron distribution is small, all electrons execute similar trajectories from the foil to the bottom surface; the small spread observed is due mainly to the distribution of initial transverse phase space coordinates. In contrast, if the electrons are reflected from the bottom surface both their angle and energy can change according to the MCNPX probability distributions, and thus the impact spots in other locations are more diffuse. For example, there is a dense impact spot with a ring-shaped extension on the top surface of the vacuum chamber. The dense spot is from the peak of the MCNPX scattering probability distributions in energy and angle, and the ring shape extension is from the tail of the tail of the distributions which allow for lower energies and a range of scattering angles. Likewise, the sparsely populated ring-shaped spot located at the –y aperture if from electrons that bounced off of the magnetic field after surface reflection, and were then re-intercepted on the bottom aperture. Note that all impact spots occurring after reflection are +x of the first surface interception. This is due to the gradient drift cited earlier.

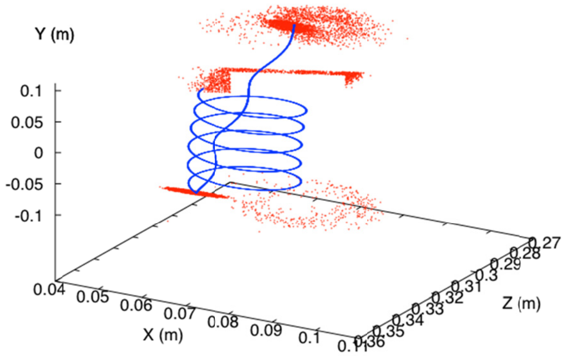

Figure 2: 3D view of the impact distribution (red points) and an example electron trajectory (blue lines).

Table 1 summarizes the loss distribution for this case. Other SNS injection configurations, not presented here, yield similar results.

Table 1: Summary of Uncaught Electron Loss Distribution.

Location	% of electrons lost
Bottom aperture	59
Top aperture	28
Foil	2
Foil assembly bracket arm	2
Foil assembly bracket	9

Table 1 also shows that 13% of uncaught electrons are predicted to intercept the foil assembly. This number is a few percent higher for the 3rd generation assembly which was observed with bracket and arm damage upon removal from beam.

An important goal of this work was to either validate or refute the hypothesis that foil-stripped electrons are intercepting local hardware after reflection on the catcher surface. Each of the 3 major impact spots seen in Figure 2 can be tied to one of the experimental observations. First, the dense spot on the bottom aperture is observed in the machine as black marks on the top plates of the catcher; multiple black marks in the real machine are likely due to injected beam spot repositioning. Second, the impact spot on the top aperture can be linked with the black mark observed at the top of the vacuum chamber; the locations agree to within the error of the known position of the black mark. Third, simulations of the 3rd generation assembly, not presented here (see ref [3]), show a high density of electron loss in the locations where the damage occurred.

In conclusion, the simulations support the hypothesis that uncaught electrons in the SNS ring injection are intercepting local hardware. Though the fraction of total uncaught electrons is unknown, for the SNS 1 MW beam even a small fraction would constitute significant power deposition on the hardware. The hazard becomes more serious for future high power machines which will produce tens of MW of beam power. As in the SNS case, it is not uncommon for the injection configuration to be tweaked away from design after operations begin. Electron catching schemes will need to be robust against such changes.

REFERENCES

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