CLEARING OF ELECTRON CLOUD IN SNS

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Abstract

In this paper we describe a mechanism using the clearing electrodes to remove the electron cloud in the Spallation Neutron Source (SNS) accumulator ring, where strong multipacting could happen at median clearing fields. A similar phenomenon was reported in an experimental study at Los Alamos laboratory's Proton Synchrotron Ring (PSR). We also investigated the effectiveness of the solenoid's clearing mechanism in the SNS, which differs from the short bunch case, such as in B-factories. The titanium nitride (TiN) coating of the chamber walls was applied to reduce the secondary electron yield (SEY).

INTRODUCTION

ORNL is constructing a Spallation Neutron Source, equipped with a high intensity proton accumulator ring. Table 1 shows its main parameters. It has a long bunch length and high beam intensity. The multipacting in such a long bunch ring differs from that with short bunch case. It is a bunch beam and the electron cloud is mainly generated by the beam induced multipacting, which differs from the coasting beam case where the electrons by gas ionization are trapped inside beam. This study investigates the clearing of electrons in the long bunched machine SNS [1].

Table 1 Main parameters of the SNS accumulator ring

Description	Value
Beam energy	1.9 GeV
Circumference	248 m
Beam intensity	2.05×10^{14}
Transverse beam size	28, 28 (mm)
Bunch length	700 (ns)
Beam pipe radius	10 (cm)

CLEARING ELECTRODE

A clearing system was applied to the SNS injection area and the BPMs were modified as clearing electrodes. We assumed a clearing electrode with a vertically uniform field in this study. The clearing field is equal to the total voltage between clearing electrodes divided by the chamber's diameter. In principle, to suppress the electron cloud, a clearing field is required equal to the maximum beam space-charge field at the wall's surface to restrain the emission of secondary electrons. An adequate clearing field should be applied to suppress the emission of secondary electrons at the bunch tail where multipacting occurs. We can estimate the electrons' energy gain [2] to find the starting time of multipacting where the total SEY exceeds unity, and then calculate the beam's space charge field near the chamber wall's surface at that moment. This space charge field is the required electric clearing field to suppress multipacting. For example, at the SNS, a clearing voltage of 8 kV is needed to complete suppress multipacting after 500 ns. In fact, the requirement on the clearing field is not directly related to the beam's potential because the electrons produced by multipacting at the bunch tail are emitted at the wall's surface and they could not be trapped by the beam's potential, even without any clearing field. The purpose of clearing field is to suppress the emission of secondary electrons instead of pulling them out from the beam's potential like trapped ions or electrons. On the other hand, a necessary condition for removing trapped electrons from a coasting proton beam or ions created by residual gas ionization in an electron machine is that the clearing electrode's electric field should be higher than the maximum field generated by the beam's space-charge because the beams can deeply trap electrons and ions at the chamber's center.

To find the correct clearing field, various clearing voltages were applied, and their effects were simulated using CLOUDLAND [3]. Fig. 1 shows the electron peak density at various clearing voltages. As a figure of merit, we use the peak line electron density to describe the clearing field's efficiency. As Fig. 1 shows, a notable feature is that this efficiency is not a monotonic function of the clearing voltage. A weak clearing field of 200 Volts reduces the line density of the electron by about a factor of 3. Subsequently, the line density increases with the increasing voltage, reaching a maximum at 2,000 Volts; it decreases again when stronger clearing fields are applied.

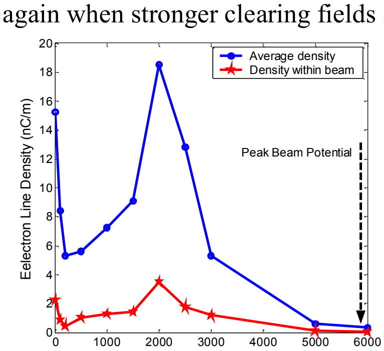

Figure 1. Variation of the peak line density of the electron cloud with various clearing potentials in the SNS's drift region.

It is not surprising that a 6 kV clearing voltage, which equals the beam's peak potential for the SNS ring, can

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suppress most of the multipacting. We expect 8 kV to complete to suppress it, as discussed above. In agreement with our estimation, we note that the peak potential of 6 kV is not necessary for clearing the electron cloud. Unexpectedly, however, we found that the clearing efficiency is higher for 200 Volts than for 3,000 Volts, and that multipacting is stronger with a 2,000 Volt clearing field than any other one.

The electron motion in a clearing field can explain these results. Electron motion can be divided into two categories: electrons bouncing between the chamber walls' surfaces with a low clearing field, and bouncing near the positive clearing electrode with a high clearing field [1]. Clearing fields can change the electron's orbit and energy at the wall surface, and hence multipacting. It may reduce or enhance electron's multipacting depends on the details of clearing field's effects.

Fig. 2 shows the transverse distribution of the electron cloud at different times for zero and 2000 Volts clearing voltage. The distribution is azimuthally uniform at zero fields. However, the electron cloud is distributed along the line of the clearing field (vertical here) at the horizontal center due to the "polarization effect" of the clearing field.

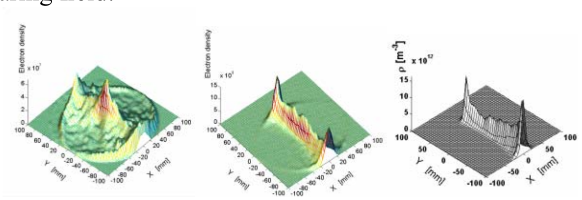

Fig. 2. Electron transverse distributions in the SNS with 2kV clearing field at 350ns (left); 560 ns (middle) and 630 ns (right).

SOLENOIDS

A 30-Gauss weak solenoid can be invaluable in confining the electron cloud by multipacting to the region near the wall and limiting the energy of electrons hitting the wall's surface to below the multipacting level. It can reduce the electron density inside the chamber by a factor of a thousand. There is a non-electron circle at the chamber's center with a radius more than the beam's transverse size. Figure 3 shows the electron's orbit and distribution with different solenoid fields. Macek's PSR experiment demonstrated that a 20-Gauss solenoid field reduces the electron signal by a factor of 50 [4]. When the periodic solenoids are arranged in the coil with their currents in the same direction, this geometry is called equal polarity configuration. When the solenoids' currents take alternative directions, it is termed an opposite polarity configuration. The electron density in the latter case is six times larger than that in the former. Importantly, most electrons stay around the chamber's center under opposite polarity; there are no electrons near the chamber's center with an equal polarity configuration as shown in Figure 4. Therefore, the solenoids should be arranged in the latter configuration in operating the real machine. Simulation shows that the electron cloud in an opposite configuration is trapped inside the solenoids, rather than in the gap between them. The distribution of electrons reflects the combined effect of the space-charge force and the solenoid fields.

Note that the electrons by gas ionization can not be cleared by solenoid. Instead of clearing, solenoid can deeply trap these electrons at the chamber center as shown in Fig. 5. Therefore, a good vacuum is highly required to reduce the number of these electrons when a solenoid is used to clearing the electrons by multipacting.

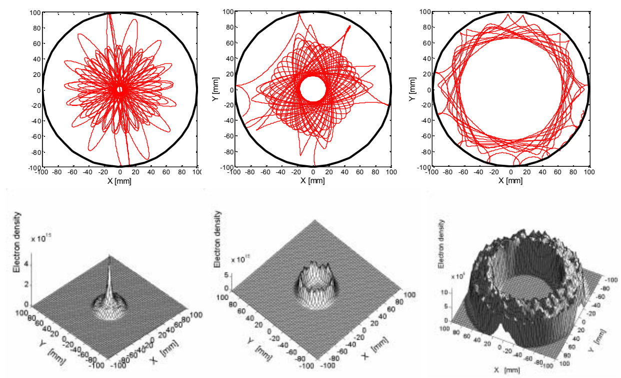

Figure 3. Transverse electron trajectories (top row) and electron cloud's transverse distribution (bottom row) in a zero (left column), 10 Gauss (middle column) and 30 Gauss (right column) solenoid field during passage through the bunch center.

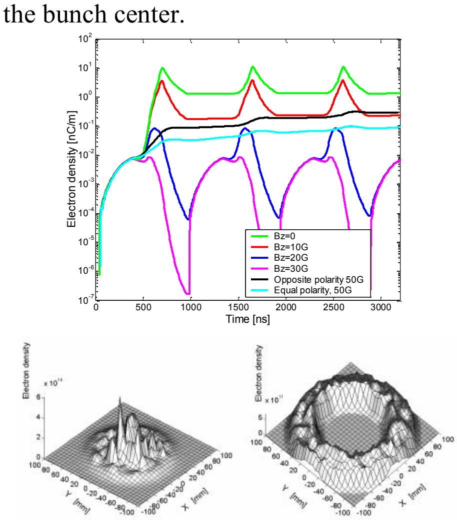

Figure 4 solenoid configuration effects

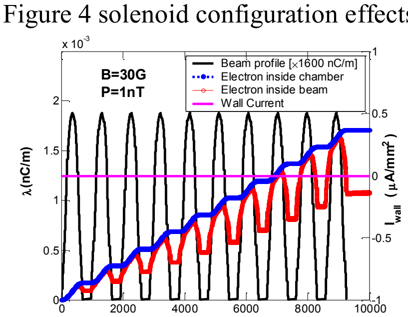

Figure 5 Trapping of electron cloud by solenoid

TITANIUM NITRIDE COATING

It is well known that the density of the electron cloud is very sensitive to peak SEY when multipacting occurs due to its exponential growth. In the absence of a space-charge effect, the electron density should increase exponentially with SEY. Most SNS ring chambers are fabricated from stainless steel, which has a peak SEY of ~ 2.5. The SEY can be reduced to < 2 if the surface is coated with titanium nitride (TiN) [5]. Figure 6 shows the electron build-up and electron line density for different peak SEYs. Electron density inside the chamber increases linearly with peak SEY, at a rate that is slower than the exponential growth due to the space-charge effect. In contrast, the average volume electron density inside the beam approaches saturation for a big peak SEY due to the strong space-charge effect. Because beam instability is governed primarily by volume density inside beam, we conclude that the beam's instabilities will saturate at certain peak SEY. However, the heat-load in SNS ring caused by the electron-cloud hitting the chamber does not saturate until the peak SEY is 2.5.

The electron energy gain with a long beam, which usually is less than the energy at peak SEY, is much smaller than that with short bunch, such as in B-Factories. Accordingly, a long beam is more sensitive to the energy at peak SEY. The energy at peak SEY has equivalent effects as the peak SEY. Figure 7 shows the electron build-up and electron density for different energies at peak SEY. Both the electron line density inside the chamber and the electron volume density inside the beam increase linearly with the decrement of energy at peak SEY. The electron volume density inside the beam does not reach saturation because the electron line density inside the chamber is not large enough. For the SNS beam, if the energy at peak SEY in Table 2 falls from 330 eV to 246 eV, the electron density inside chamber will increase from 12 nC/m to 67 nC/m. The effect is the same as increasing the SEY from 1.74 to 2.07. However, the effect on electron density inside beam is stronger than increasing the SEY from 1.74 to 2.5. Therefore, a bigger energy at peak SEY can significantly reduce the beam's instability.

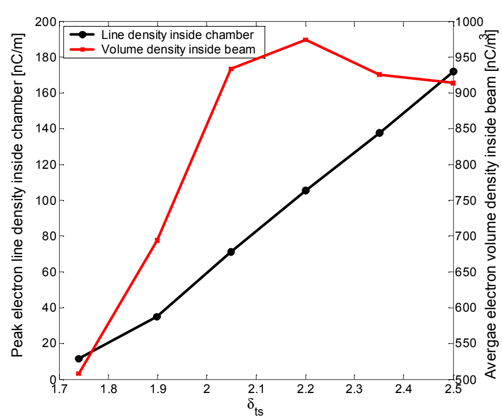

Figure 6 The effects of peak SEY on density.

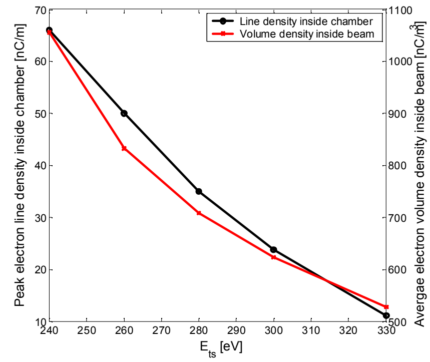

Figure 7 Effects of energy at peak SEY on density.

In addition to the coating of stainless surfaces, the injection ceramic chambers and the extraction ferrite kickers are also coated with TiN. The TiN coating is divided into small strips with gaps using custom grid masks which provide a coating on 70~90% of surface while still maintaining a resistance of 100Ω or higher between the strips. The electron line density at the extraction kicker will be a factor of 4~10 lower with 70%~90% of surface covered with TiN as compared with un-coated ferrite surface as shown in Fig. 8.

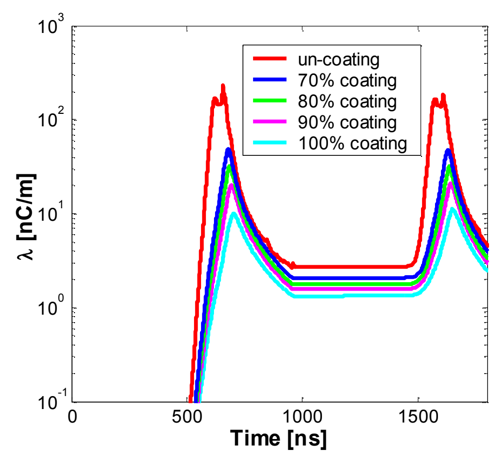

Figure 8 The electron line density inside the extraction kickers with ferrite surface un-coated, 90% coated and 100% coated, showing a reduction by a factor of ten with TiN coating.

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