PRELIMINARY ESTIMATION OF THE ELECTRON CLOUD IN RHIC

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Abstract

The electron cloud, caused by beam-induced multipacting is suspected to be one of the sources of pressure rises in RHIC. This paper estimates the possible electron cloud in RHIC, and investigates various parameters related to electron multipacting.

INTRODUCTION

Since 2001 when researchers at RHIC first try to double the bunch number from 55 to 110 by reducing the bunch spacing from 216 ns to 108 ns, increases in vacuum pressure were observed. These pressure rises exceed the acceptable limit for the accelerator's operation. They occur faster with a high intensity beam and shorter bunch spacing, and also faster after two beams are injected, which effectively results in even shorter spacing in the common regions (e.g., the interaction region). The electron cloud, due to beam-induced multipacting, is suspected to be one of the sources of pressure rises in RHIC. Increases in pressure caused by electron multipacting have been firmly established at various storage rings [1-2]. During RHIC's operation, the pressure rise, typically occurring at beam injection, is very sensitive to the intensity and spacing of the bunch in proton-, deuteron- and gold-beams. Electron multipacting mostly seems to be involved. This effect is the result of the coupling of the beam with a cloud of electrons in the beam's vacuum chamber. For certain modes with short bunch spacing and high intensity, a high cloud density will distribute the beam. The pressure rises at RHIC are high enough to prevent the accelerator's operation and this imposes a limitation on the planned future upgrade to the high intensity operation [3]. We estimate the possible electron cloud in RHIC, and discuss our investigations of various parameters related to electron multipacting.

THRESHOLD OF MULTIPACTING

In a static model, the energy received from the bunch by an electron near the beam chamber's surface is

$$\Delta E \approx 2 m_e c^2 r_e^2 \frac{N_b^2}{r_b^2} \tag{1}$$

where r_e is the classic radius of the electron, N_b is the bunch intensity, and r_b is the radius of beam chamber. RHIC has a long bunch spacing of 108 ns. Studies show that an electron hits the chamber's wall before the next bunch arrives. Multipacting happens only during a short period after the beam's passage when the electrons are swept to the wall surface. In such a ring with long bunch spacing, the reflected electrons play a very important role in the accumulation of the electron cloud.

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Eq. (1) gives an energy about 23 eV for N_b=10×10^{10} and r_b=60 mm. The simulated electron energy at the wall is much larger than this value because electron multipacting is random [4]. Table 1 gives the thresholds for multipacting under different conditions derived by the simulation program CLOUDLAND [5] assuming a peak secondary emission yield (SEY) of 2.3, and yield of reflected electrons with near-zero energy of 0.6. The threshold depends on the SEY parameters. However, the dependence of multipacting on other parameters is qualitatively correct. Observations show that the limitation of pressure on the bunch intensity is about 3~4 times that of the threshold shown in Table 1. Simulation reveals that stronger multipacting usually happens with a short bunch length in a chamber with a small radius. On the other hand, multipacting is insensitive to the beam's transverse size. The threshold with an ionic Au^{+79} beam is much lower than that with a proton beam because electron multipacting is driven by the beam's space-charge force. Figure 1 shows the electron build-up with different bunch lengths, chamber radii and bunch spacing. Reducing of the bunch spacing from 216ns to 108 ns increases the peak electron density by a factor of 3, which explains the pressure rises when the bunch spacing is reduced.

Table 1: Multipacting threshold.

Particle	σ_{full}[ns]	σ_x [mm]	R[mm]	N_{th} ×10^{10}
P+	15	2.4	60	~ 3.3
P+	7.5	2.4	60	~>2.0
Au^{+79}	18	2.4	60	~>0.037
Au^{+79}	9	2.4	60	~ 0.03
P+	15	1.2	60	~ 3.0
P+	15	2.4	40	~2.9
P+	7.5	1.2	40	~1.9
P+(Dipole)	7.5	2.4	60	~<33

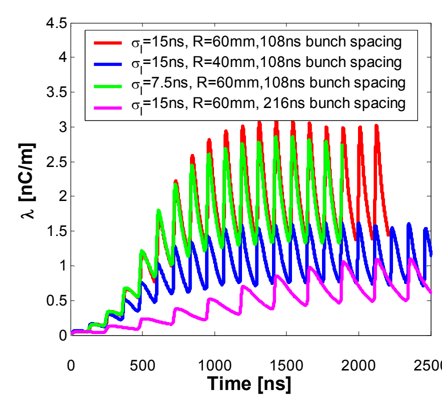

Figure 1 Electron cloud build-up with different bunch lengths and chamber radii. The proton beam has an intensity N_b=2.0×10^{11} and bunch spacing 108/216 ns. The peak SEY is 2.3 and the energy at the peak SEY is 300eV.

EFFECT OF BUNCH DENSITY

Figure 2 shows the effect of bunch density on the average density of the electron cloud. Electron density increases quickly after the threshold for multipacting is reached; this agrees with the measured electron signal during the beam injection shown in Fig. 3. The measured pressure grows exponentially, indicating strong multipacting. The rise in pressure depends on the beam's pattern. It is highly sensitive to bunch current and bunch spacing. A similar nonlinear increase in pressure was observed in the KEKB low energy ring [6].

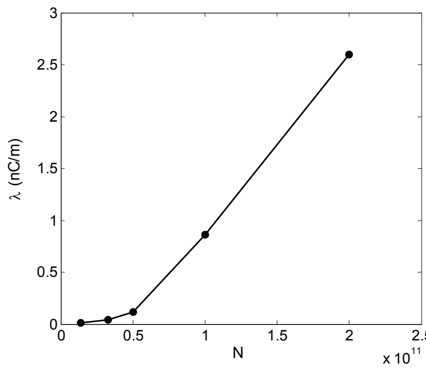

Figure 2 Electron density vs bunch intensity for a proton beam with 108ns spacing.

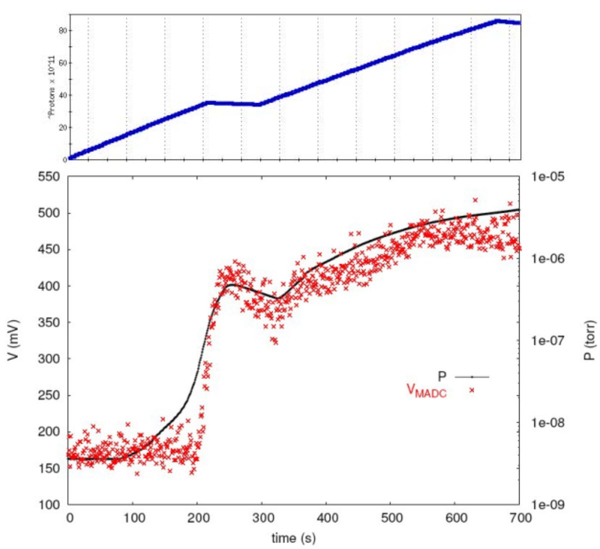

Figure 3 Measured electron signal and vacuum pressure during beam injection. Top: Beam intensity vs time. Bottom: Electron signal and pressure vs time.

BEAM PATTERN EFFECT

Simulations were done for different beam patterns to check the saturation level of the electron cloud. The results show that a long train with a short gap is preferable; in other words, the more uniform the beam's pattern, the lower is the peak electron density. Multipacting is sensitive to the intensity of single bunches, rather than to the average beam current. Figure 4 compares two different beam patterns. They have the same bunch spacing of 3 RF bucket spacing. One has 12 bunches in the train and followed by a gap of 24 RF bucket spacing, while the other has 14 bunches in the train and followed by a gap of 18 RF bucket spacing.

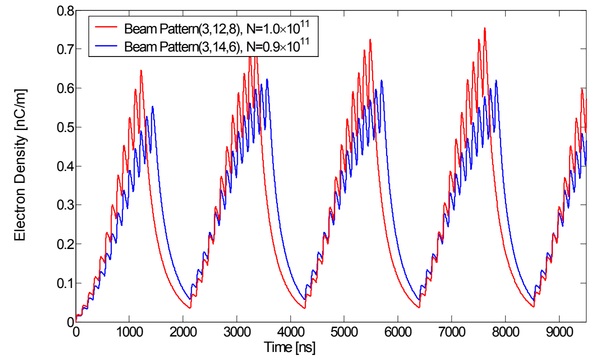

Figure 4 Beam pattern effect on electron build-up in a proton beam with a bunch spacing of 108ns.

POSSIBLE SOURCE OF THE PRIMARY ELECTRONS

In RHIC, the saturation level of the electron cloud is sensitive to the yield of the primary electrons. When the production and loss rates are in equilibrium, the electron cloud saturates. Simulations were carried out to benchmark the measured electron current when electrons hit the chamber's surface by changing the primary electron yield. Two kinds of mechanism were investigated: electrons generated by gas ionization and electron produced by beam loss. Studies show that the numbers of electrons produced by gas ionization are neglectable. The main sources of primary electrons are those generated by beam loss.

Fig. 5 shows the electron current at the chamber surface. It is comparable to the experimental findings [7]. A yield of primary electrons 8×10^{7} e/m is used. The assumed beam loss per turn is 2×10^{-6} and proton-electron rate is 1×10^{6}. Bunch spacing is 108ns, and intensity is 8×10^{10}.

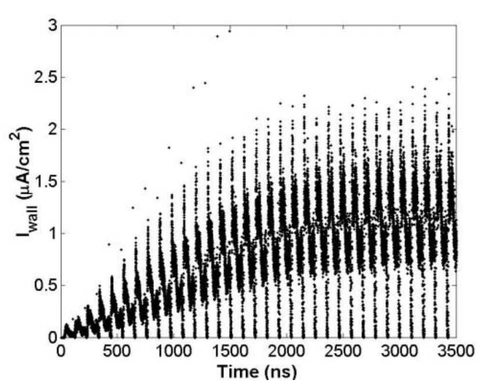

Fig. 5 Electron current at the chamber surface

EFFECT OF A SOLENOID

During the 2003 summer shutdown, we installed a solenoid in sections: IR12, BI12, YO12, YO1, BI1, BO2, YI2, and YO4 of the RHIC. The solenoid used was the

Kapton wire (bakeable) that was wrapped around the RHIC's vacuum chamber in 1m segments unless constrained by pipe supports. The solenoid and the DC power supply provide up to a 6000 Ampere turn per meter, equivalent to a 75 gauss axial field. Figure 6 shows the effect of a 30 G uniform solenoid on electron build-up and its transverse distribution. The solenoid can significantly suppress the electron multipacting by confining the electrons near the walls' surfaces. Experiments show that even a few Gauss of a solenoid field can effectively change the vacuum pressure in some gauge.

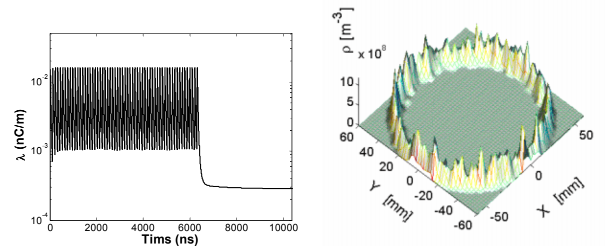

Figure 6 Electron build-up and distribution with a 30G solenoid field

ELECTRON CLOUD IN THE INTERACTION REGION

A rise in pressure in one of the interaction regions, PHOBOS, was frequently observed and affected the d-Au run. The interaction region is a 12m-beryllium pipe that has a bigger peak SEY because baking does not improve the SEY. A quadrupole-type magnet is located close to the interaction point (IP), 0.6m from IP. The gauges are sited on both sides of the pipe. Experiments demonstrated that the pressure rise is sensitive to this magnet. With the Au^{+79} ion, the pressure goes up when the magnet is on. However, it goes down with a proton beam when the magnet is on. However, the effect of the magnet on the beam was not observed [8]. Simulation shows that the magnet's field can trap more electrons with the Au^{+79} ion. The findings were similar for a proton beam. We can not explain the mechanism causing the drop in pressure when the magnet is on during the proton run. Further studies are underway.

ELECTRON CLOUD WITH A DIPOLE MAGNET AND ELECTRODE

Electron multipacting in the dipole magnet is much weaker than in the field-free region. The electron cloud is distributed at the chamber's horizontal center where the electron's energy at the wall is around 100 eV. On the other hand, there are two stripes of electron cloud near the horizontal center in the dipole magnet of the B-factories [5] and CERN SPS [9]. Simulation shows a weak electric field can clear the electron cloud in RHIC due to its long bunch spacing (Fig. 7).

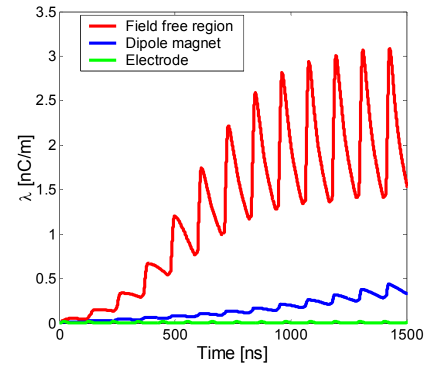

Fig. 7 Comparisons of electron cloud build-up in a drift region, dipole magnet and electrode.

SUMMARY

A preliminary study was made of possible electron multipacting in RHIC using the program CLOUDLAND. The electron cloud is one possible source of the observed rise in vacuum pressure during the accelerator's operation. Electron multipacting occurs in the drift region and electrons accumulate in the quadrupole due to trapping. Weak multipacting occurs at the horizontal center of dipole magnet. Both a solenoid field and clearing field can suppress the accumulation of an electron cloud.

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