Two-stream instabilities workshop,

KEK, 11-14 September, 2001

A 3D MODEL FOR THE EP INSTABILITY IN PROTON ACCUMULATOR

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Introduction

The LANL PSR has a fast instability that limits the proton beam intensity per pulse. A similar instability was observed at the AGS Booster in BNL. A probable cause of this instability is the interaction of a large electron density in the vacuum chamber with the proton beam, which leads to a transverse mode coupling instability between the circulating protons and oscillating electrons trapped in the proton potential well. Multipacting drastically increases the electron density, which, in turn, leads to the instability. The purpose of this paper the simulation code is to assess the risk of the e-p instability in the SNS ring.

Electron Accumulation

(1) For the coasting beam, multipacting occurs due to the proton beam instability. Electrons could accumulate during beam injection in the proton beam potential well, and after reaching some threshold density, could generate unstable coupled oscillations between themselves and the proton beam. In this case the lighter electrons gain large amplitudes and strike the vacuum chamber wall, producing an avalanche of secondary emission (SEM) electrons, resulting in the large transverse amplitudes of the protons.

(2) **For the bunched beams there are two scenarios for the electron accumulation - single pass and multi-pass electron accumulation.**

a) Single pass accumulation is related to the multipacting on the trailing edge of the proton beam. For the case of a constant longitudinal density, electrons with zero initial kinetic energy at the vacuum chamber wall oscillate across the vacuum chamber gap through the circulating beam with zero energy gain. If the longitudinal bunch density is increasing the electrons lose their energy. If the longitudinal bunch density is decreasing, the electrons gain energy after traversing the vacuum chamber. It is speculated that multipacting can significantly increase the number of electrons on the trailing edge of the proton bunch if the energy gain of the electrons is above 50 eV for an aluminium vacuum chamber. If at some point there is a significant number of electrons at the vacuum chamber while the proton beam center passes, this number of electrons will be increased by a tremendous factor, depending on the material of the wall. Primary electrons, initiated by beam losses or other reasons, produce an avalanche of secondary emission electrons. The process continues up to the point when the electron density is comparable with the density of the proton beam. It is probable that this mechanism occurs at the stripper foil point, where the density of electrons is high from the very beginning, and at the ceramic and aluminum parts of the vacuum chamber with high SEM coefficient. Almost all electrons accumulated at single pass disappear in the beam gap due to their own space charge.

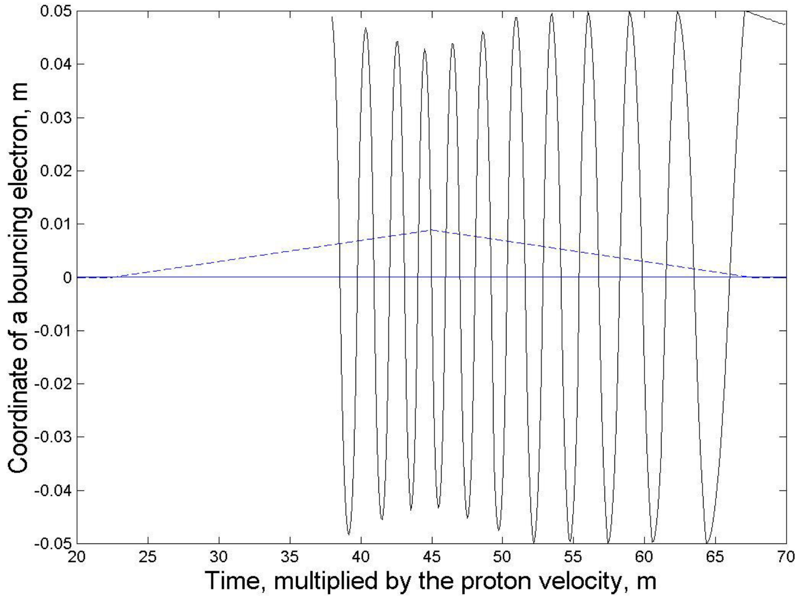

Figure 1 Motion of an electron in the fields of the proton beam.

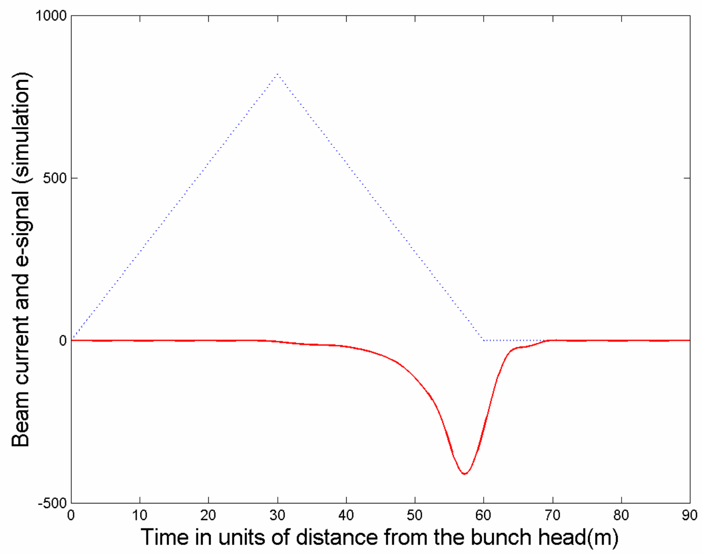

Figure 2 Proton bunch longitudinal distribution (blue) and the electron signal (red).

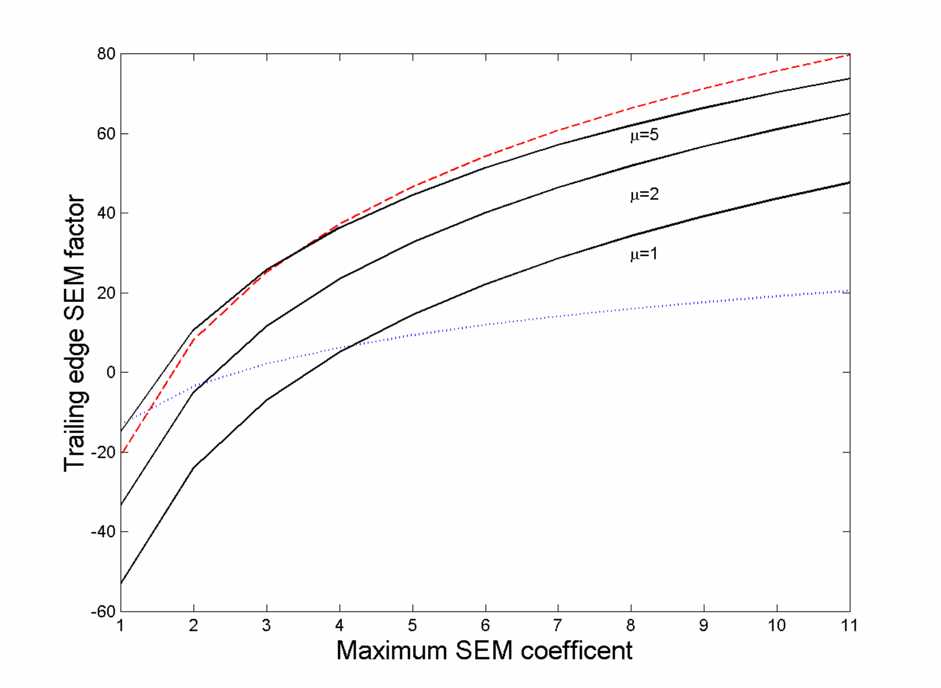

Figure 3 Secondary emission factor versus the maximum SEM coefficient of various materials. Solid line is for the SNS ring, dashed blue line - for the PSR.

$$Longitudinal \quad distribution = C \cdot (1 - \frac{s^2}{L_b^{\ 2}})^{\mu}$$

b) Multi-pass accumulation of electrons is a more complicated process. If the SEM coefficient (or the number of initial electrons at the wall) is too low to produce any significant electron density during a single pass, these electrons can accumulate in a multi-turn process. In the first significant papers on the PSR instability it is assumed that some mechanisms for electrons to be stable in the strong field of the bunched proton beam should exist. For example, some portion of the proton beam straying into the gap was listed as a probable candidate for this mechanism.

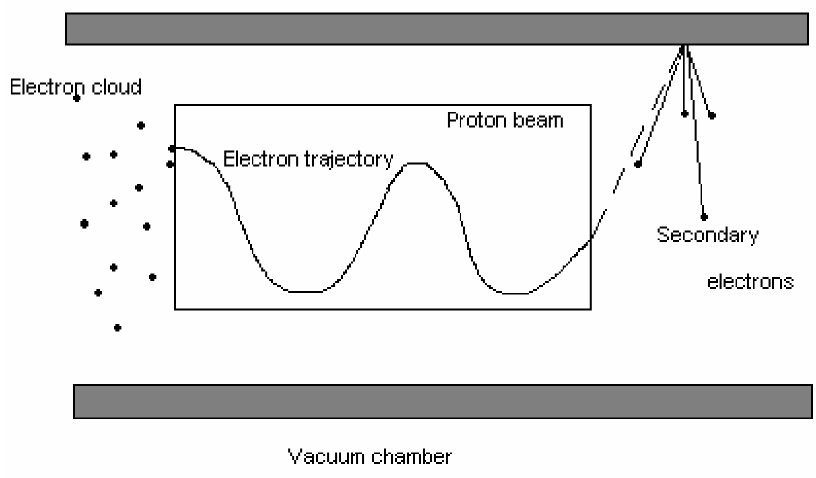

Figure 4 Schematic motion of electrons in the field of the proton bunch.

LEVELS OF SATURATION

a) The single turn mechanism saturates at electron densities comparable to the proton density.

b) The multiturn electron density is lower, and can be estimated by equating the gap duration to the time required for an electron to drift back to the chamber. One can obtain the degree of compensation $\chi = 0.003\sqrt{E_{out}(eV)}$, where E_{out} is the energy of the secondary electron. If we equate this to rms energy of 3.5 eV, it will give us χ=0.56*10^{-2}, so the electron density is less than one percent of the proton density. But still, that could be enough for instability to occur.

Finally, we note one simple consequence of the above scenario. If one had some amount of proton beam in the gap, it would definitely increase the saturation level in multi-turn accumulation. If the number of protons in the gap is about 1%, it would give the double number of electrons in the multi-turn scenario. Since the ratio of multi-turn and single turn electrons is not clear it is not possible to predict exact dependence of the e-p instability threshold on the proton beam in the gap. One can definitely say that 1% of the proton beam in the gap can increase the electron density by approximately 100%.

SNS APPROACH.
NEED FOR ADVANCED SIMULATION

The threshold SEM coefficient for SNS was calculated to be in the range 1.8-2. Consequently, every piece of the vacuum chamber should be coated with TiN, which has a maximum SEM of about 1.5. Because of convolutions, the unshielded bellow coefficient could be about 20% higher than that number. If the bellow surface is coated with TiN and is well conditioned (the maximum SEM is about 1.5), one can expect the resulting coefficient not to exceed 1.8. Thus, it is likely that the SNS ring will not undergo electron cloud build-up in the bellows. However, since 1.8 is a marginal value, it is worthwhile to install electron detectors to check this conclusion. In addition, the ring will have a relatively high vacuum (5×10^{-9} Torr) to reduce the initial electron density, a beam-in-gap kicker to reduce number of electrons surviving the gap, and an electron collector near the stripping foil.

Places of the probable electron accumulation: collimators, stripping foil region, ceramic pieces.

Code is needed to predict the probability of the ep instability to occur.

Code is needed to test tools to mitigate or eliminate the instability.

(DOE reccomendation)

THE 3D MODEL FOR PROTON-ELECTRON MOTION

We intend to incorporate the models of space charge simulations (SNS 3D PIC code ORBIT), SLAC and LBNL secondary emission simulation, LANL, PPPL and BNL ep simulation.

In order to reproduce realistic results we need to keep the following features of the electron-proton motion:

1) **3D space charge of the proton beam – since it strongly influences the thresholds (M. Blaskiewicz, H. Qin, etc.)**
2) **Bunched proton beam and realistic energy distribution**
3) **2D space charge of the electon beam to reproduce its saturation**
4) **Secondary emission, including its subtle features such as energy distribution, angular dependence, etc.**

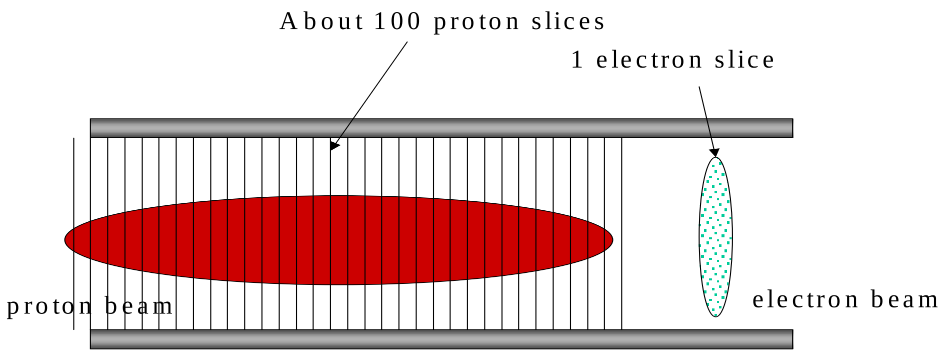

Figure 2 Schematic drawing for the calculation model

STATUS OF THE COMPUTER PROJECT

1) Main computer code (ORBIT), which takes into account all essential nodes of accelerator, is written.

2) The 3D space algorithm is implemented.

3) The algorithms have been carried over to parallel version in UAL/ORBIT (joint BNL/ORNL accelerator software).

4) The electron cloud node is under development.