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The electron cloud effect in PEP-II*

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ABSTRACT

We present a brief account of our simulations for the electron-cloud effect in the arcs of the PEP-II positron ring. This article summarizes Ref. [1].

1 Introduction

The electron-cloud effect (ECE) was first observed at the Photon Factory (PF) at KEK [2]. The ECE manifests itself as a fast transverse coupled-bunch instability that arises only when the machine is operated with a positron beam. Unlike the ion-induced instability, which is observed when the PF is operated with an electron beam, the positron beam instability persists even if there is a substantial gap in the bunch train. Experiments at BEPC [3] have confirmed the basic features of the effect seen at the PF. It is now widely believed that the origin of the ECE is an electron cloud that develops inside the vacuum chamber, coupling the transverse motion of the bunches. A related instability, caused by trapped electrons, is observed at CESR [4].

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2 Simulations for PEP-II

Over the past 3 years or so we have developed and applied a simulation code to study the ECE in PEP-II [1] and other machines. This code follows the same calculational methodology originally described by Ohmi. [5] In our code we pay particular attention to the secondary electron yield (SEY) of the vacuum chamber surface because, as our simulations have shown, PEP-II is in a parameter regime in which the ECE instability growth rate is close to (but below) a "threshold" beyond which it grows very quickly as a function of the peak value of the SEY.

Our simulation code is 3-dimensional, takes into account the elliptical geometry of the vacuum chamber, optionally includes the space-charge force of the electron cloud, and can simulate the electron cloud in a dipole bending magnet or in a field-free region.

2.1 Input parameters

The positron ring vacuum chamber is of elliptical cross-section and has an antechamber on the outboard side of the ring. [6] Each positron radiates, on average, 2 photons upon traversing any given dipole bending magnet with a spectrum whose critical energy is 4.8 keV. About 99% of these photons escape through the antechamber slot and, to first approximation, play no role in the ECE. The remaining 1% of photons are emitted with low energy and wide angle, and remain inside the chamber. These photons yield photoelectrons upon hitting the vacuum chamber walls, ultimately leading to the ECE. The average energy of these photons is ~ 16 eV, assuming a low energy cut-off of 5 eV, corresponding to the work function of the metal.

The ECE depends on 3 parameters pertaining to the surface material, namely: the quantum efficiency Y', the photon reflectivity R and the peak SEY $\hat{\delta}$. The PEP-II positron ring arc vacuum chambers are made of aluminum, whose SEY was measured at SLAC [7] to be $\hat{\delta} \simeq 2$. Our early simulations showed that, in this case, the ECE would lead to a very fast instability. Consequently, the decision was made to coat the chambers with TiN, whose measured SEY is [7] $\hat{\delta} \simeq 1.1$. In our results discussed below we assume this value for $\hat{\delta}$.

We do not have measurements of Y' and R. However, our simulations show that, for $\hat{\delta} \simeq 1.1$, the instability growth rate scales linearly with Y'. We have assumed a value $Y' = 1$, which is probably pessimistic. We have estimated the growth rate for the two extreme cases $R = 0$ and $R \simeq 1$. As described below, there is only a $\sim 30\%$ variation in the results within this range of R.

2.2 Results

We represent the arcs by a very simplified model consisting of nothing but field-free pumping sections, each being 7.15 m long, and dipole magnets of length 0.45 m. We have not yet included other magnets such as quadrupoles.

The growth rate is dominated by the pumping sections owing to their larger overall length. For $Y' = 1$, and assuming nominal PEP-II beam parameters, [6] our present estimate ranges in $\sim 1000 - 1300$ s^{-1} when R ranges in $0 - 1$. This growth rate is within the range controllable by the transverse feedback system. The contributions to the growth rate from other magnets and from other sections of the ring remain to be evaluated.

3 Discussion

Owing to the TiN coating, the average SEY (*i.e.*, the SEY folded with the energy-angle spectrum of the electrons hitting the walls of the chamber) is < 1. Thus the walls act as net absorbers of electrons, and therefore the electron cloud density reaches a saturation when the average number of electrons absorbed in one bunch spacing equals the number of photoelectrons generated by the bunch in the same time interval. This saturation is reached after ~ 60 bunches following injection into an empty vacuum chamber. Our simulations show that the average saturation density is $\sim 3\%$ of the beam neutralization level in the pumping sections, and $\sim 9\%$ in the dipole bending magnets. At these relatively low densities the space-charge forces can be safely neglected.

The simulations also show that, if the chambers were not coated with TiN, the electron cloud would be in a runaway condition, akin to beam-induced multipacting, [8] by virtue of which the electron cloud density grows exponentially in time until it reaches an average value comparable to the beam neutralization level after ~ 100 bunch passages. At this point the growth stops due to the strong space-charge forces. By scaling our results with the average electron density at equilibrium, we estimate that the growth rate in the absence of the TiN coating would be $\sim 20-30$ times larger than with the coating (this is probably a worst-case estimate; we have not carried out a reliable simulation of this situation).

As mentioned above, the antechamber slot allows $\sim 99\%$ of the radiated photons to escape. Thus, in the absence of an antechamber, there would be 2 orders of magnitude more photons in the vacuum chamber resulting, perhaps, in ~ 10 times more photoelectrons. This implies that the growth rate would be 10 times larger than without the antechamber. However, if the chamber were not coated with TiN, the benefit of the antechamber would be negligible *vis à vis* the ECE because the electron cloud density would reach the neutralization level anyway.

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