Comment to the Kinematics of e-p Multipacting

S. Heifets, G. Stupakov

Stanford Linear Accelerator Center, Stanford University, P.O. Box 4149, Stanford, CA 94309

V. Danilov

Oakridge National Laboratory

Abstract. Simple comments are given on the mechanism of e-p multipacting. We emphasize that beam instability is a factor which may be important for this effect. The comments are results of the discussion which authors have during the Workshop.

It was emphasized during the Workshop that the beam induced multipacting may be important in hadron machines. Indeed, the avalanche multiplication of electrons in the beam pipe is well known [1] and has been extensively studied recently in positron storage rings [2]. The electron cloud may lead to coherent transverse oscillations in the long train of bunches with the growth rate by an order of magnitude larger than that of conventional instabilities. The flux of electrons to the walls leads also to additional heating of the beam pipe and out-gassing of neutrals. The last process may deteriorate pressure but, at the same time, provides additional mechanism of surface cleaning.

Primary electrons are generated by synchrotron radiation or in the inelastic collisions with residual gas. They can be accelerated by the electric field of a bunch and produce secondary electrons provided their energy exceeds threshold energy $E_{th}$.

Secondary electrons have energy distribution centered at $E \approx 5 - 10$ eV with width also of a few eV. A gap in the train provides cleaning if its length $L$ is large enough to let secondary electrons reach the wall at radius b, $L > b\sqrt{me^2/E} \approx 30$ m for $b \approx 10$ cm.

If bunch spacing is smaller, then secondary electrons get a kick from the beam and can produce the next generation of electrons. The threshold energy $E_{th}$ may be defined as energy where yield of secondary electrons exceeds one. The energy
dependence of the yield $\eta$ is more or less the same for all metals: it grows initially and then saturates at the level $\eta \approx 1.2$ at $E > 150 - 200$ eV. Aluminum has exceptionally low $E_{th} \approx 50$ eV and high maximum yield $\eta \approx 1.5$ at $E \approx 400$ eV. The process may be enhanced if the time of flight to the wall is multiple of the bunch spacing.

Acceleration by the beam in the lepton machines with short bunches can be described as a kick. The kinematics in hadron machines is different because bunches are long. As a result, electrons trapped in the potential well of the beam oscillate with frequency $\omega/c = \sqrt{2en/n_0}$ where $n$ is the local charge density in the beam. This frequency is high, and electron can make 10–20 oscillations within the length of the bunch.

In this case, longitudinal variation of the bunch density $n(s)$ is adiabatic compared to the fast oscillations. Hence, energy and amplitude of oscillations $A$ of a trapped electron changes along the bunch while $\omega A^2$ remains (approximately) constant. Hence, $A \approx n^{-1/4}$, and electron energy $E \approx \sqrt{n(s)}$. Therefore, electrons trapped in the head of the bunch with large amplitude and low energy increase their energy approaching the center of the bunch. The maximum energy can be quite high, much larger than $E_{th}$. However, due to adiabaticity, amplitude and the energy go to their initial values in the tail of the bunch. Such low energy electrons cannot multiply. This is totally opposite to the situation in the positron machines.

Situation may be drastically different if adiabaticity is approximate or does not hold at all. We want to emphasize that the effect of the trapped electrons on the beam may provide a mechanism to break adiabaticity. Indeed, interaction of the electrons of a cloud and the beam may lead to the two-stream instability [3] and distort distribution of the bunch. Even small ripples, especially enhanced to the tail of a bunch, may lead to violation of adiabaticity.

It is important, therefore, to consider the problem of multipactoring as a self-consistent dynamic problem where distribution of the beam is affected by the electron cloud. Computer simulations should include this effect to produce a reliable result.

This work was supported by the US Department of Energy, Office of Basic Energy Sciences, under contract # DE-AC03-76SF00515.

REFERENCES

1. see, for example, O. Grobner, Beam Induced Multipacting, LHC Project Report 127, May 1997
2. Proceeding of the International Workshop on Collective Effects and Impedance for B-factories, (CEIBA-95), Tsukuba, 1995
D. Sagae and A. Tennykh, Observation of the coherent beam-ion interaction in CESR storage ring, Nucl. Inst. and Methods A 344 (1994), pp. 459-469