A COUPLED BUNCH INSTABILITY DUE TO BEAM-PHOTOELECTRON INTERACTIONS IN POSITRON STORAGE RINGS

K. Ohmi
KEK, National Laboratory for High Energy,Physics,
Oho, Tsukuba, Ibaraki 305, Japan

Abstract

In positron storage rings with high current and multi-bunch, very many photoelectrons are produced at a beam chamber and interact with the positron beam. The beam chamber will be filled with the photoelectrons by passing bunches successively. This paper presents a result of computer simulation in which the photoelectrons may cause a coupled bunch instability with high growth rate.

1 INTRODUCTION

We discuss a possibility that photoelectrons cause a coupled bunch instability in positron storage rings[1]. In Photon Factory in KEK, an coupled bunch instability has been observed only on positron beam operation[2]. This instability may be identified to that we discuss here. The photoelectrons are produced by synchrotron radiation of positron beam at a vacuum chamber. This instability may be very serious for high current positron storage rings operated with multi-bunches. The correlation between bunches is caused by passing the positron beam through the photoelectron cloud. It is well-known that positive charged ions produced by an electron beam causes a coupled bunch instability so-called two beam instability[3]. The ions are trapped in the electric potential of electron beam and are accumulated up to a threshold of the instability. The other hand photoelectrons are not trapped by a bunched positron beam due to their light mass. However the photoelectrons produced at a chamber is a very huge number, thus may become a sufficient density to cause the instability without trapping. In the case of a positron storage ring with a stored energy of a few GeV, one positron emits a few hundred synchrotron photon in each revolution. Photoelectrons are produced when the photons hit a vacuum chamber wall. If the production rate is assumed to be 0.1, a few dozen of photoelectrons are produced by a positron in each revolution. In the case of multi-bunch operation, the bunch passes through the beam chamber successively, thus the photoelectrons are supplied continuously. The photoelectrons propagate in the beam chamber and are absorbed into its surface at about 10-100ns later of their production. The problem is how many photoelectrons exist in beam chamber and how interact with beam.

We can not express this phenomena with a simple model by small number of oscillators as done in ion instability. Thus we perform numerical analysis with a computer. We can consider several ways to simulate the phenomena.

- Both of photoelectrons and positron beam are expressed by macro-particles. We track two kind of particles with coulomb interaction.
- Consider beam as rigid, while photoelectrons are expressed by macro particles. Calculate the force of the interaction between photoelectrons and beam. Photoelectrons move with feeling the force, while the rigid beam feels the reaction force which is summed for all photoelectrons[4].
- Model is the same as 2nd one. Assume the dipole force which beam feels is linearly depend on the transverse displacement of the rigid beam and introduce the idea of the wake force.

1st method is most accurate one but computer resource consuming, while 2nd and 3rd are approximated ones. If we use 1st method, it is impossible to get a reliable result without an enough statistics of macro-particles. In the case of this problem, photoelectrons distribute whole of chamber. Thus we are required much number of macro-particles to reject the statistical noise and are much CPU time. If we performed it, we got information for not only dipole motion but also deformation of the beam. In the method of 2nd and 3rd, we are limited to investigate only a dipole motion of beam, while CPU time is reduced. It depends on the problems which method is appropriate. 2nd method can treat nonlinear force for dipole displacement of the rigid beam, while required to track the beam up to longer than the growth time. In 3rd method, the force is assumed to be linear for a dipole displacement of the beam. In our problem, since the photoelectrons distribute in wide region, the condition will be satisfied. The tracking of photoelectrons is enough to perform during only a range of wake force, thus computation time will be extremely reduced.

Now we use 3rd method, that is, we calculate wake force of beam-photoelectron interaction with simulation.

The wake force has information of unstable mode and growth rate of the instability.

2 PRACTICAL SIMULATION

We present a simulation result with parameters of the low energy ring of KEKB (Table 1). Let us consider a beam chamber with a diameter of 10cm. We investigate the motion of photoelectrons in the model chamber. All RF bucket is assumed to be filled by a number of positron uniformly. At first image that a bunch passes through the chamber. Photons emitted by the bunch illuminate the beam chamber, resulting photoelectrons are produced. The photoelectrons are allocated by macro-particles on a computer. When second bunch comes at the position, the photoelectrons produced by the first bunch interact with the bunch. The second bunch produces new photoelectrons at the same position of the chamber. By repeating this process, photoelectrons are filled in the chamber. Here we consider interactions between beam and photoelectrons, but not between each photoelectron. Photoelectrons which arrive at the surface of the chamber are eliminated from the memory. After repeating some times, the number of photoelectrons saturates, that is, the production and elimination become equilibrium. The number of the repeating process depends on the model. The saturation is known by counting the total number in the chamber in each repeating. Fig.1 shows the increase of the number of macro-photoelectrons. In this example after passing about 100 bunches, the distribution mostly saturates and it is shown in Fig.2.

Table 1 Parameters of KEKB-LER.

Energy	3.5GeV
Circumference	3016.26m
Positron in a bunch	3.3×10^{10}
Emittances	$1.8/0.36\ \mathrm{x}10^{-8}$ m
Damping time	80-40ms (depend damping wiggler)
Tunes	45.52/45.08
Bunch spacing	0.59m
Harmoic number	5120

Next consider that a bunch with a transverse dipole amplitude passes through the saturated distribution. We call it loading bunch. The distribution is disturbed by the loading bunch. Bunches which pass after the loading bunch feel a force from the disturbance. If the force is linear for the displacement and satisfy superposition rule, we can treat the force as the wake force by analogy of the impedance problem. The wake force is shown in Fig.3 and have good linearity for the displacement.

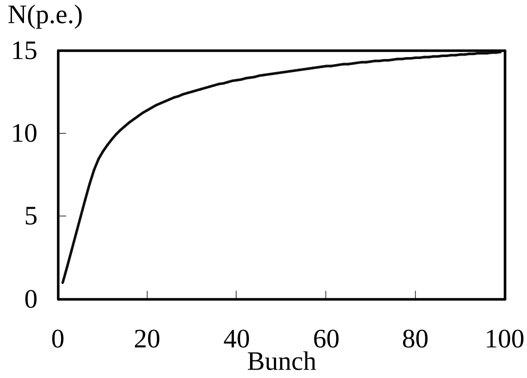

Fig.1 Number of macro-photoelectron in the beam chamber. It is normalized by the number of the photoelectron produced by a bunch.

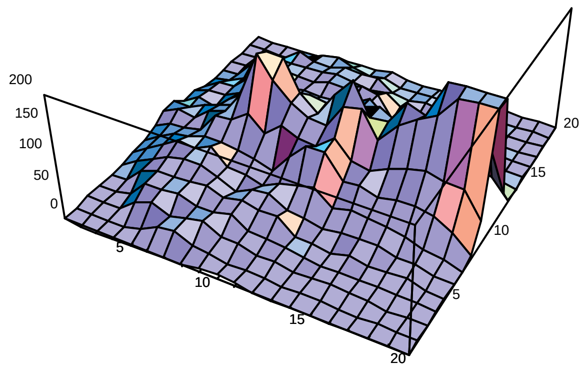

Fig.2 Distribution of photoelectrons in the vacuum chamber. The mesh size is $5\mathrm{x}5\mathrm{mm}^2$ and beam position is (10,10). Photoelectrons are produced at (20,10).

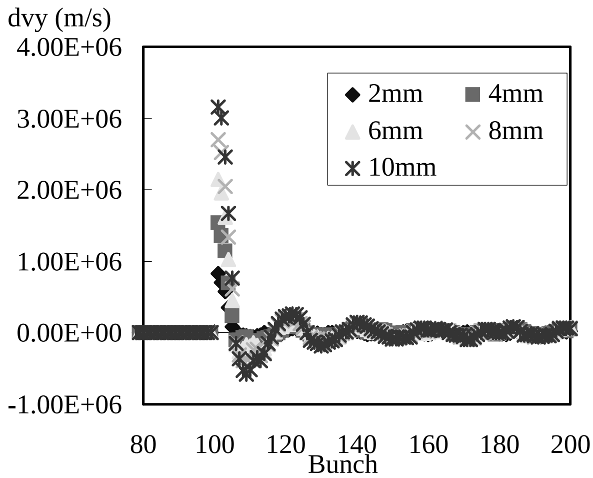

Fig.3 Vertical wake force for various initial displacement.

Here we consider how many the macro-particles are required to get the wake force. If the macro-particles of N distribute with gaussian of the deviation of 5cm, the mean position are fluctuate by $1/\sqrt{N}$. When we try to obtain the wake force with a displaced bunch of 0.5mm, the number N should be much larger than 10000. Practically $5x10^4$ or 10^5 macro-particles are produced by a bunch in the simulation. We will understand it will be difficult to perform the simulation with the 2nd method described in Sec.1. We are required to track macro-particles of 10^5 during passing the number of bunch of harmonic number times damping time. Poor statistics causes a noise of the wake which may lead unphysical instability.

We comment that the characteristics of the wake by the photoelectron cloud. When a bunch with positive displacement, the distribution of photoelectron will be polarized to positive direction. The following bunches are attracted by the distribution, thus the wake near the loading bunch is positive. The photoelectron interact with beam during the time of a few bunch passing, thus the range of wake will be that time. Some of photoelectrons return after their first interaction, that is, they are trapped though short time. We can observe such the effect in the figure.

Unstable modes and its growth rates of the coupled bunch instability can be estimated by the wake force. In the case of KEKB, mode number of 4000-5000 become unstable. The growth rate depends on the number of photoelectrons which contribute the instability. If the photoelectron production rate for an incident photon is 0.1 and all of them contribute the instability, the growth rate is about $10^4 s^{-1}$.

3 DISCUSSION

We did not discuss effects of the space charge between photoelectrons and of the magnetic field. Concerning the motion near to the beam, beam charge is dominate from the photoelectron’s one. Residual field of the magnet is about a few gauss at about 1m from its edge. Thus this simulation which do not included them will be reliable in a degree, but should include them to get better result. Concerning magnetic field, we consider in KEKB case, and result a few dozen gauss of magnetic field recover this problem[5]. We consider to insert magnets to apply the magnetic field. Concerning the space charge effect of photoelectrons, we have tried to consider by slicing the chamber with mesh to calculate a coulomb potential. However the wake function depends on mesh size now, thus we have not get a reliable solution yet. However wake force near to the loading bunch is remarkably reduced, thus we can expect a reduction of the growth rate by the space charge effect.

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