THE PROPOSED EXPERIMENTAL STUDY ON BEAM-PHOTOELECTRON INTERACTIONS IN BEPC

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Abstract

A vertical collective effect suspected as photoelectron instability (PEI) has been observed at Photon Factory (PF) of KEK in recent years. This phenomena may impose a limitation on the performance of the proposed B-Factories or T-c Factories. An experiment has been planned to test it using positron beam at Beijing Electron Positron Collider (BEPC) in 1996 under the cooperation between IHEP and KEK. Preliminary simulation results have shown that the PEI may occur in BEPC on the total beam current level of 40 mA over more than 20 bunches. The instrumentation for observation of PEI is jointly prepared by both sides of IHEP and KEK. The machine study has been scheduled and the experiment will progress under the conditions of the best machine performance.

1 INTRODUCTION

The vertical coupled-bunch instability has been observed in the PF at KEK for years when operated in a positron multibunch beam mode. This instability has a rather low threshold current and causes an increase of the vertical beam size. The spectrum of the betatron sideband shows a broadband distribution and suggests that this instability does not attribute to the HOM of the RF cavity or the vacuum components. A partial filling of a positron beam has little effect to suppress the instability [1].

A large number of photoelectrons are produced when the synchrotron radiation hits the inner wall of the beam tube. Typically, one photoelectron is created out of ten photons at PF. The following physical model has been proposed to explain the mysterious instability observed at PF in terms of the "beam-photoelectron interaction" [2]: photoelectrons created by the passage of a bunch receive attractive forces from the successive bunches and forms a crowd around the beam axis. While photo-electrons are constantly produced by passages of bunches, some of them hit the tube surface and get lost. After a while, the numbers of newly-born and died photo-electrons reach the equilibrium, and the distribution of photo-electrons becomes stationary when there is no coherent motion of bunches.

If a bunch passes through the stationary photoelectron distribution with an offset from the beam axis, the distribution is disturbed and affects the transverse motion of the following bunches. The coherent interaction between bunches and the crowd of photoelectrons can be formulated in the same manner as for the conventional beam instabilities using the concept of wake potential. One can accordingly derive a dispersion relation, the mode number and its frequency. The growth rate of the instability can be estimated from the imaginary part of the frequency shift.

There are two B-factories being constructed at KEK and SLAC respectively. Several proposed colliders as the T-c Factory are discussed in the world; one of them is suggested to be built in Beijing, China. All of these particle factories have two rings each, one for electrons and another for positrons. Since these colliders will be operated with a very large beam current in a multibunch mode, the investigation of the photo-electron interaction and the possible instability is very important. The basic machine parameters of BEPC [3] in comparison with PF, KEK B-factory (KEKB) [4] low energy ring, Beijing Tau-charm Factory (BTcF) [5] for the PEI testing are listed in Table 1.

Table 1 Basic Parameters of BEPC in Comparison with PF, KEKB(LER) and BTcF

		PF	KEKB	BTcF	BEPC
E	GeV	2.5	3.5	2.0	2.2
C	m	187	3016	384	240
ε_{x0}	nm	130	18	163	76
ν_y		3.31	46.08	11.2	5.18
τ_y	ms	7.8	89.8	31.0	17.7
f_{RF}	MHz	500	509	500	200
h		312	5120	641	160
$I_{beam}(e^+)$	mA	300	2600	570	40-100
N_{bunch}		312	5120	86	20-160
S_b	m	0.6	0.59	3.78	12-1.5

From simulation results presented in section 2, the photoelectron interaction might be observed in BEPC at certain conditions of multibunch positron beam operation. An experimental study had been proposed to survey this phenomenon, to confirm the mechanism and to predict the importance for the future electron positron colliders like B-Factories or T-c Factories.

2 SIMULATION OF PEI FOR BEPC

Taking advantage of a computer code developed for the beam-photoelectron interaction study [2], the simulation has been carried out for BEPC. Firstly, the stationary distribution of photoelectron is simulated. Then, the beam-photoelectron wake force is computed. Finally, the growth rate of PEI is calculated by using this wake force.

2.1 Photoelectron Distribution

The number of photons emitted by a positron throughout a ring circumference is given by

$$N_\gamma = \frac{5\pi}{\sqrt{3}}\alpha\gamma \qquad (1)$$

where α is the fine structure constant and γ is the relativistic energy. In the case of BEPC at 2.2 GeV, the N_γ calculated from eq.(1) is 285. This means, there are about 7 photons emitted in each bending section.

Assuming the emission probability η=0.1 for aluminum, which is the case of BEPC, the total number of photoelectron $N_{e,\gamma}=1.4\times10^{11}$ for the current of 1 mA in a bunch. As mentioned earlier, the motion of the photoelectrons is unstable owing to the over focusing from the positron bunches. In the multibunch case, the photoelectrons are supplied constantly by the SR hitting the wall of vacuum chamber emitted from the successive positron bunches. Figure 1 displays the simulated stationary distribution of the photoelectrons in BEPC. We use 10000 microparticles to represent the photoelectron produced by each bunch and assume the energy of photoelectrons has a Gaussian distribution of 5±10 eV.

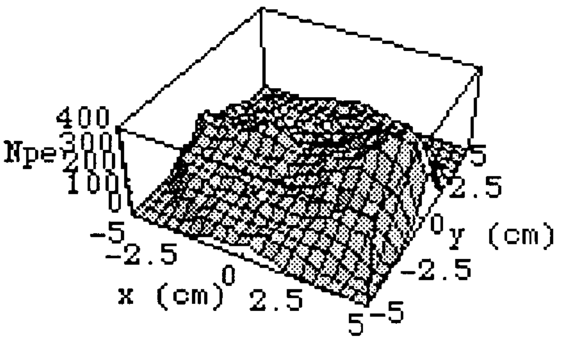

Fig. 1 Stationary Distribution of Photoelectrons

2.2 Beam-Photoelectron Wake

The photoelectrons with the distribution act as a medium of bunch-to-bunch interactions. The wake force is computed by introducing a small perturbation dy to the driven bunch and simulating the motion of the trailed bunches. Figure 2 shows the vertical wake force simulated for beam current of 80 mA equally distributed in uniformly distributed 40 bunches in BEPC, while a dy=0.5 mm is introduced onto the 20-th bunch .

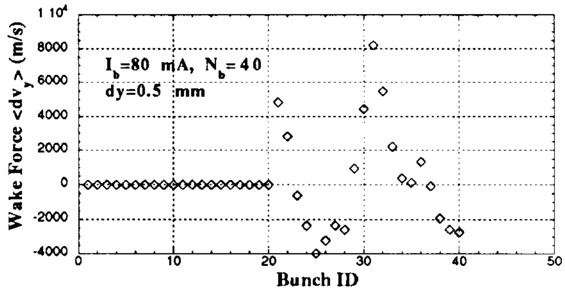

Fig. 2 Simulated Vertical Wake Force

2.3 Growth Rate of PEI

The coupled-bunch instability caused by the wake force can be derived from the dispersion relation [6]:

$$\Omega_m - \omega_\beta = \frac{1}{4\pi\gamma\nu_y}\frac{N_{e\gamma}}{N_b}\sum_{n=1}^{n_0}\frac{d\bar{v}_y}{dy}\left(-\frac{ncT_0}{N_b}\right)e^{2\pi ni(m+\nu_y)/N_b} \qquad (2)$$

where the mode is defined by

$$y_n^{(m)}(t) = e^{2\pi imn/N_b}\, y_0^{(m)}(t) \qquad (3)$$

and

$$y_j^{(m)}(t) = \tilde{y}_j^{(m)} e^{-i\Omega_m t} \qquad (4)$$

By using the wake force described in Fig. 2 for dv_y in eq.(2), the growth rate of the PEI can be calculated, shown in Fig. 3. The PEI growth rate of 5000 s^{-1} for I_b=80 mA and N_b=40 in BEPC is much larger than the SR damping rate of 60 s^{-1}.

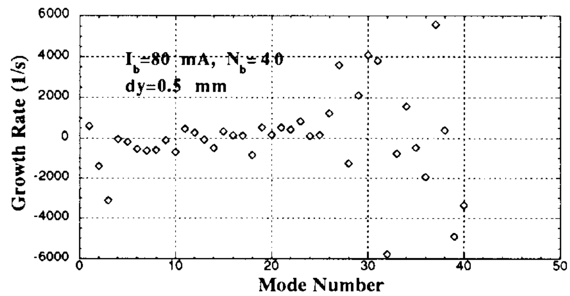

Fig. 3 Growth Rate of PEI in BEPC

2.4 Discussion

Beam-photoelectron interactions are simulated for BEPC with different beam currents I_b and bunch number N_b. The wake force and growth rate as functions of beam currents (for N_b=40) and bunch number (for I_b=80 mA) are shown in Fig. 4 and Fig. 5 respectively. In Fig. 4, the linear relation can be seen. Figure 5 shows that the PEI growth rate increases rapidly with bunch number when $N_b \leq 40$. It can be deirved from Fig. 4 and Fig. 5 that $1/\tau \approx 1000\ s^{-1}$ in BEPC at I_b=40 mA and N_b=20, and PEI should be observed.

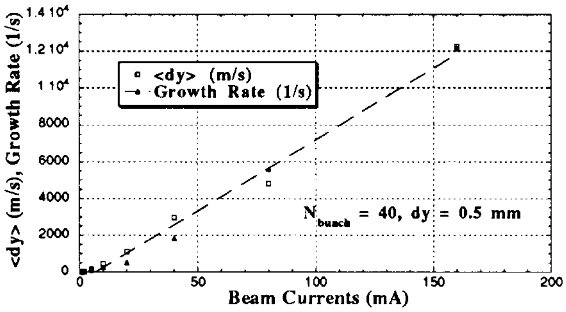

Fig. 4 Wake Force and Growth Rate vs. Beam Currents

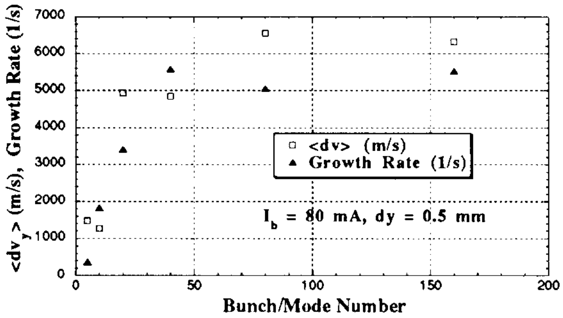

Fig. 5 Wake Force/Growth Rate vs. Bunch/Mode Number

3 PROPOSED EXPERIMENTS

In BEPC, which is operated as a collider as well as a synchrotron radiation source, the maximum single beam current of 85 mA and the maximum multibunch beam current of 150 mA have been already reached for years. Under the best machine performance, it seems possible to provide a variety of the bunch loading pattern on the total beam level of 40 mA and over more than 20 bunches which are necessary conditions for the PEI observation from the simulation results.

According to the theory and the simulation, the PEI in BEPC looks like a coupled bunch instability which is caused by a wake force whose effective range is several tens successive bunches after a driven bunch. Spectrum of betatron sidebands caused by this coupled bunch motion should have a broadband characteristic and the growth rate of the PEI is not dependent on the beam energy. To observe the coupled bunch motion by the PEI, we are planning to use mainly two instruments, namely a spectrum analyzer and a single path beam position monitor.

The spectrum analyzer HP8568B will be used to make a Fourier analysis of the beam signal from a button pickup. It has a band width of 1.5 GHz. A system of the single path beam position monitor is being prepared. The center-of-mass beam position of every bunch will be stored by each turn in a filter-memory board which is being developed for a bunch feed back system of KEKB. It has an ADC, custom-made demultiplexers and memories of 20 MB. As subsidiary instruments, a synchrotron light monitor and a streak camera will be useful to observe the beam behavior.

To distinguish the PEI from other instabilities, the coupled bunch instability will be carefully studied. The coupled bunch instabilities caused by the HOM's of RF cavities have been observed at the different filling pattern in BEPC and the HOM's which caused the instabilities were identified. The modes at the frequency of 332.7 MHz and 397.8 MHz may be dangerous, which will be checked again at the experimental conditions. It is found from the simulation study and the observation that the growth rate of the transverse resistive wall instability in BEPC is much slower than the synchrotron radiation damping time at the experimental conditions.

The experiment is planned in four periods as follows. The first period, in the middle of June will be targeted to check the coupled bunch instabilities of electron beam caused by the HOM's of RF cavities. The PEI would be observed in the second period by the end of June. The spectrum analyzer will be the main instrument in these periods. During the summer shut down, the preliminary experimental results will be analyzed and the instrumentation will be improved accordingly. The third period of the experiment will be planned around the beginning of December 1996 during which the PEI will be surveyed in details using the spectrum analyzer , the single path beam position monitor and other instruments such as the streak camera. The last part of the study of the PEI based on the results of former experiments is expected by the end of January 1997.

4 SUMMARY

An experiment of beam-photoelectron interactions with the cooperation between IHEP and KEK will be progressing in BEPC recently. The results of the experiment will help both design and construction of some advanced lepton colliders like B-Factories and T-c Factories.

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