THE EXPERIMENTAL STUDY ON BEAM-PHOTOELECTRON INSTABILITY IN BEPC

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Abstract

A vertical coupled bunch instability explained as the photoelectron instability (PEI) was observed in the Photon Factory at KEK. To further investigate the instability, the experiments on the PEI have been carried out in Beijing Electron Positron Collider (BEPC) with the collaboration between IHEP, China and KEK, Japan. Many interesting phenomena have been observed for different sets of parameters.

1 INTRODUCTION

A vertical instability was observed in the PF at KEK when the machine was operated with the multibunch positron beam years ago[1] and the similar instability has been also observed in BEPC recently. This instability is a coupled bunch oscillation with a low threshold current of a few 10 mA in both machines. The broad distribution of the betatron sidebands can be observed when the instability occurs. From the spectrum of the betatron sidebands, one cannot find any HOM at the corresponding frequency in RF cavities. It is also hard to be suppressed even by filling positrons partially in RF buckets. This instability does not occur in electron beam at the same conditions. It was explained as the photoelectron instability (PEI)[2].

A computer code has been developed to simulate the PEI. The number of photons emitted by a positron throughout a ring circumference is proportional to the energy of the photon.

The photoelectrons start at the surface of beam pipes and are propagated while receiving the electric force from the following positron bunches. One can consider the force as the wake field to cause the coupled bunch instability. The characteristics of the instability can be estimated by applying the existent instability theory as [3]

$$\Omega_m - \omega_y = \frac{-n_e c T_0}{4\pi\gamma\nu_y n_b N_b} \sum_{k=1}^{k_0} k \frac{d\bar{v}_y}{dy} e^{2\pi k i (m+\nu_y)/N_b} \qquad (1)$$

where N_b is the bunch number, n_e the particle number in a bunch, k the range of the wake, ν_y the vertical betatron tune and v_y the velocity of the photoelectron.

The particle factories like B-factories and Tau-charm factories will be built in the world and will be operated at the high current with many bunches of the electron and positron being stored in their respective rings. Therefore, one should investigate the PEI in the existing positron rings. To study the PEI experimentally, a series of machine studies on the PEI in BEPC were proposed [4].

The BEPC has been operated as a collider as well as a synchrotron radiation source with the maximum single beam current of 150 mA from 1.3 to 2.2 GeV. It is possible to provide a variety of the bunch loading pattern on the beam level of the PEI observation. The PEI is simulated for BEPC with the different beam current I_b and the bunch number N_b[5]. In the BEPC diagnostic system, there are several types of beam monitors which have been working well for years. The instruments for the observation of the PEI are prepared by both sides of IHEP and KEK. At present a spectrum analyzer, HP8568B with 1.5 GHz bandwidth, connected with a button pickup is used for the beam spectrum observation.

The machine studies have been progressed in BEPC to survey the PEI in details since last June under the cooperation between IHEP and KEK. The investigated effects on the PEI include: chromaticities, bunch space, emittance, beam energy, RF frequency, distributed ion bumps, betatron tunes, magnetic field, RF voltage, etc. This paper describes the experimental observations and some analyses.

2 OBSERVATION

2.1 Main Characteristics of the PEI

The coupled bunch instability was observed in the positron beam with a low threshold current about 9.4 mA at 1.3 GeV and the full filling with 160 bunches uniformly[6]. The vertical betatron sidebands $nf_0 \pm f_y$ by each revolution frequency were observed on the spectrum analyzer where f_y is the vertical betatron frequency and f_0 the revolutionary frequency. The typical observed vertical sidebands compared to the corresponding growth rate calculated with the phenomenological model are shown in Figure 1, where the solid curves are the calculated growth rate and the vertical lines are the distribution of the observed vertical sidebands. The sidebands were observed at the beam current of 9.6 mA with 158 bunches. The vertical oscillation can also be observed on the synchrotron light monitor. The stability is quite sensitive with the vertical chromaticity at the threshold current and significantly depends on the bunch spacing.

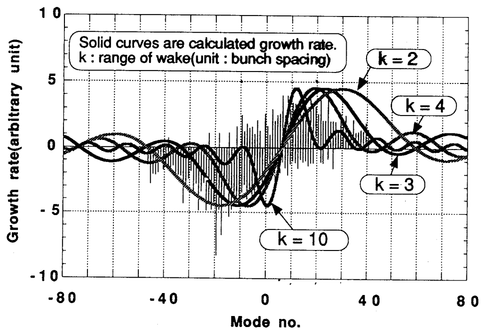

Figure 1: The vertical betatron sidebands and the calculated growth rate of the instability

2.2 Influence of the Chromaticity

The chromaticity influence on the instability is clear especially near the threshold current. The vertical sidebands disappeared when the vertical chromaticity increased by 1 or 2 from the normal value of 4 at the beam current slightly above the threshold of the instability. On the contrary, the vertical sidebands appeared when the chromaticity decreased at the beam current slightly below the threshold. In this way, the threshold current of the instability can be easily determined by adjusting the chromaticity. We did many tests of the chromaticity effect at the different conditions and near the threshold current of the instability. The mechanism of the chromaticity is understood as the head tail damping and the Landau damping.

2.3 Effect of the Bunch Spacing

Most observation of our experiment is done under the condition of the full filling with 160 bunches uniformly. To investigate the bunch spacing dependence, we injected the positron to every other two buckets, i.e. 80 bunches uniformly in the ring. The threshold current of the instability is about 40 mA as the vertical betatron sidebands appeared when the ξ_y changes to 2.8. This result can be explained as the wake field of the photoelectron decreases quickly along the bunch spacing. However, this effect is much stronger than it was predicted by the simulation [5].

2.4 Energy Dependence

To survey the energy dependence of the instability, we scan the beam energy from 1.3 GeV to 2.2 GeV at the beam current about 15 mA. The amplitude of the vertical sidebands slightly decreased at 2.0 GeV and can be affected by the chromaticity. At 2.2 GeV the vertical sidebands disappeared. The sideband distribution is shown in Figure 2. It shows that the sidebands of the instability do not depend on the energy obviously at the beam current above the threshold. We also scan the energy from 1.55 GeV to 2.1 GeV at the beam current about 10.3 mA which is near the threshold. The vertical chromaticity was changed at several energies to obtain the threshold value at which the sidebands disappear. The relation between the beam energy and the vertical chromaticity at the threshold value is shown in Figure 3. It can also be seen that the energy influence on the instability is not very strong. This is another feature of the PEI which can be distinguished from other single beam instabilities in the storage ring.

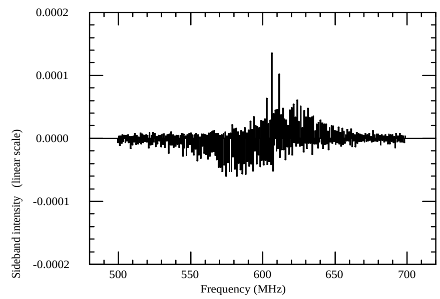

Figure 2-a: Sidebands at the energy of 1.55 GeV

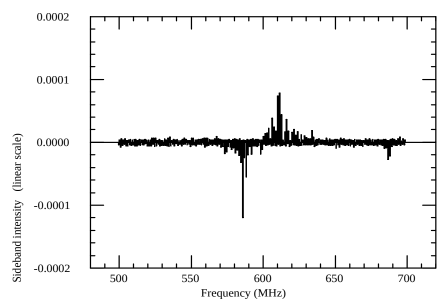

Figure 2-b: Sidebands at the energy of 2.0 GeV

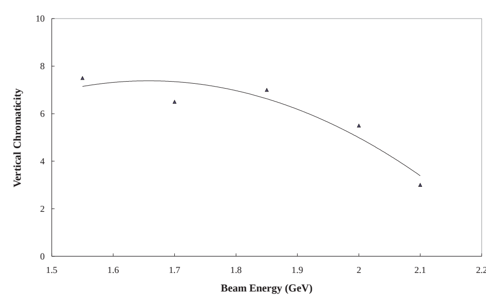

Figure 3: Energy dependence of the PEI

The number of the photon is proportional to the beam energy while the beam instability gets weaker at higher energy from Eq. (1). The beam emittance and the radiation damping time are scaled with square and third power of the beam energy. The number of photoelectrons increases with the beam energy. The energy dependence of the instability should be considered synthetically in this way.

2.5 Influence of the RF Frequency

If the distance between the center of the position beam and the wall of the beam tube is changed, the distribution of the photoelectron should be modified. We change the beam orbit by changing the RF frequency. When the beam current is near the threshold, we change the RF frequency ±20 kHz respectively which corresponds to a horizontal orbit change of ±4 mm in average. The amplitude of the sideband is a little weaker at the RF frequency change of –20 kHz than that of +20 kHz as shown in Figure 4. These effects should also be synthesized with the emittance because the emittance variation can be raised from the frequency change.

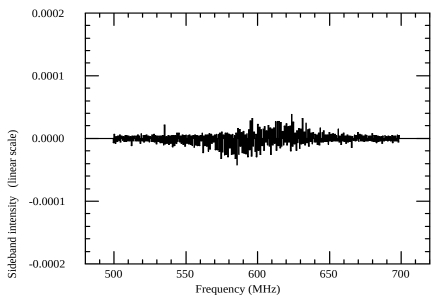

Figure 4-a: The RF frequency influence of –20 kHz

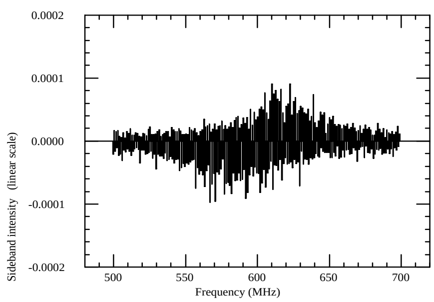

Figure 4-b: The RF frequency influence of +20 kHz

2.6 Other Related Effects

It was reported[7] that the leakage electrostatic field from the distributed ion pump traps the photoelectron and then the photoelectron instability could be resulted. The structure of the BEPC distributed ion pump is similar to that of the CESR but the calculated leakage electrostatic field is about 50 times weaker at the beam orbit center[8]. The distribution of the vertical sidebands was compared in the case of the pumps being turned on and off, but the phenomena of the instability were not changed any more.

The observation shows that the transverse and longitudinal tunes do not affect the vertical sidebands of the PEI when they are changed in a stable region. The phenomena of the instability are not influenced when the RF voltage is changed. The horizontal magnetic field effect on the PEI was also tested by increasing the field of all vertical correctors to 10, 20 and 40 Gausses, there was no experiment evidence to be observed. The threshold currents are almost the same at the conditions of a bunch train with the same bunch spacing but different bunch current and different bunch gap. The emittance dependence of the instability has been observed, but the effect is not clear because the sextupole configuration is also changed simultaneously.

2.7 Beam Spectrum in Electron Filling

The different phenomena were observed in the electron beam under the same conditions as the position beam. Many observation is carried out above the PEI threshold current with the electron beam. The vertical sidebands were only observed at $2f_{rf}$ and $3f_{rf}$ but not at other revolution harmonics. It shows that the instability is only for the position beam as an unique characteristic in position storage rings.

2.8 HOM of RF Cavity

To distinguish the HOM of RF cavity effect on the PEI, a positron beam near the threshold current of the instability was stored and the HOM signal from cavities was observed through loop pick ups below and above the threshold of the instability. No signals corresponding to the HOM was observed. This observation indicates that the PEI does not relate to the HOM of BEPC cavities.

3 DISCUSSION

The positron multibunch instability observed in BEPC is very similar to that observed in PF. The dependence of the instability on the related parameters is studied in more detail. The experiment in BEPC shows that the observed instability seems to be a common phenomenon in positron storage rings, so it is very meaningful to study the instability for such modern positron rings like B factories and Tau-charm factories. Further analytic and simulation studies are in progress.

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