Studies on electron cloud instability in BEPCⅡ *

LIU Yu-Dong(刘瑜冬)1) YUE Jun-Hui(岳军会) WANG Na(王娜)

(Institute of High Energy Physics, CAS, P.O. Box 918, Beijing 100049, China)

Abstract Electron Cloud Instability has been studied in the operation of BEPC. The BEPCⅡ began the commissioning in November 2006 and the positron beam current has reached 500 mA. Because of such a high beam current, some instabilities such as ECI, bunch lengthening et al, have appeared during the operation. The experimental investigation on ECI during the commissioning of BEPCⅡ will be reported in this paper.

Key words electron cloud, sideband, coupled bunch instability, feedback system, blow up

PACS 29.20.Dh, 29.27.Bd, 21.10.Tg

1 Introduction

The electron cloud was built up from the accumulated electrons created by the synchrotron radiation and secondary electron emission due to the absorption of the primary electrons on the inner wall of vacuum chamber. The electron cloud will interact with the bunch during the passage of the positron bunch train and cause the oscillation of the beam. The different bunch oscillation will be coupled together by the transfer of the electron cloud, so the coupled bunch instability is produced in the positron beam. The coupled bunch instability has been investigated during the BEPC and KEKB LER operation with a narrow bunch spacing train[1, 2]. Another instability, blow-up of the bunch size, was also observed in the KEKB LER and BEPC positron ring and that has become one of the serious problems limiting the luminosity for colliders[3, 4]. The Beijing Electron Positron Collider (BEPC) has been upgraded to a double-ring machine (BEPCⅡ) and the luminosity will be enhanced by two orders of magnitude, about $10^{33}\text{cm}^{-2}\cdot\text{s}^{-1}$. Since November 2006, the BEPCⅡ has started the commissioning with the positron and electron beam. In January 2008, the beam current reached 500 mA×500 mA in collision mode. Some instability similar to ECI has appeared during the operation. In this paper some experimental results on coupled bunch instability and bunch size blow-up will be introduced. The coupled mode distribution was measured and compared during the electron and position beam commissioning. The bunch by bunch position recorder was used during the experiments and the bunch by bunch feedback system in BEPCⅡ has a clear effect to suppress the instability.

2 Experimental condition in BEPCⅡ

The usual bunch filling pattern used in the experiment was a 4 buckets (8 ns) equally spaced pattern with a total bunch number of 99 bunches without empty gap and the bunch spacing can be easily reduced to 2 buckets (4 ns) with injecting the empty buckets between the neighbouring bunches. Table 1 gives the basic parameters of BEPC BPR during the experiments.

Table 1. The basic parameters of BEPCⅡ BPR.

parameters	value
beam energy E/GeV	1.89
circumference C/m	237.6
bunch spacing L_{sep}/ns	2—8
normal bunch current/mA	0.5—5
average bunch length σ_z/mm	15
IP bunch sizes $\sigma_{x,y}$/mm	0.379, 0.0465
harmonic number H	396
synchrotron tune Q_{s}	0.034
tune $Q_{x,y}$	6.54, 5.64
RF voltage V_{rf}/MV	1.45

Received 6 January 2009

* Supported by National Natural Science Foundation of China (10605032)

1) E-mail: liuyd@mail.ihep.ac.cn

3 Experimental observation on ECI

The first experimental observation on coupled bunch instability caused by electron cloud was performed in January 2008. When the BPR of BEPCⅡ is uniformly filled with a multi-bunch positron beam, a kind of coupled osculation with the appearance of vertical betatron sidebands can be found clearly. Fig. 1(a) shows the vertical sideband mode distribution observed on the spectrum analyzer. In this figure, the positive and negative values of sideband amplitudes correspond to the left sidebands $mf_0 - f_\beta$ and right sidebands $mf_0 + f_\beta$, respectively, where f_0 is the frequency of revolution, f_β the transverse betatron frequency and m is an integer. Fig. 1(b) gives the mode distribution of electron beam which is injected with the same bunch filling pattern as positron beam.

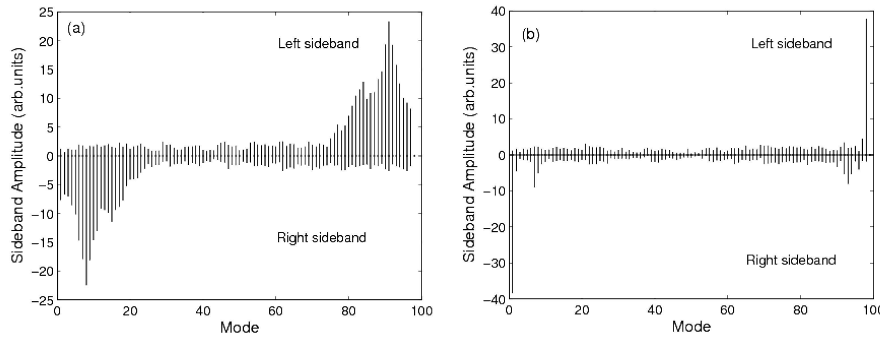

Fig. 1. Mode distribution of positron and electron beam (a: positron beam; b: electron beam).

Comparing Fig. 1(a) and (b), it's clearly seen that the mode distribution of positron beam is much broader. On the other hand, there are some other feathers on the instability of positron beam, such as a low threshold current ($I_{\rm th}$: ∼35 mA with 99 bunches, 8 ns bunch spacing; $I_{\rm th}$: ∼29 mA with 198 bunches, 4 ns bunch spacing) and strong dependence on the bunch spacing. All these feathers and mode distribution are similar to the ECI ever observed in BEPC[1]. From the above-mentioned experimental results, it can be concluded that the coupled instability observed in BEPCⅡ is caused by the electron cloud. With the bunch by bunch oscillation recorder, all the bunch positions in 4096 turns can be stored and the mode distribution also can be obtained by FFT analyses of the data. The results are the same as the mode distribution from spectrum analyzer.

It is well known that another serious problem caused by the electron cloud is the bunch transverse size blow-up along the bunch train which has ever been observed in BEPC[3]. In the experiments, a Hamamatsu C5680-11 streak camera was used to measure the bunch vertical size directly. When a 60-bunch train was injected in BPR, increasing the bunch current from 2 mA to 9 mA, corresponding to the beam currents from 120 mA to 540 mA, the vertical size of head and tail bunches were captured by the camera. By comparing the vertical size of the head and tail bunch, there is no clear blow-up in different beam current conditions. That means the density of electron cloud is not over the threshold. By the FFT method to analyze the data from the bunch by bunch oscillation recorder, the betatron tune can be taken along the bunch train. Fig. 2 shows the betatron tunes along the bunch train. It is clear that there is no tune shift along the bunch train, which also confirms that there is no bunch size blow-up with the beam current below 500 mA.

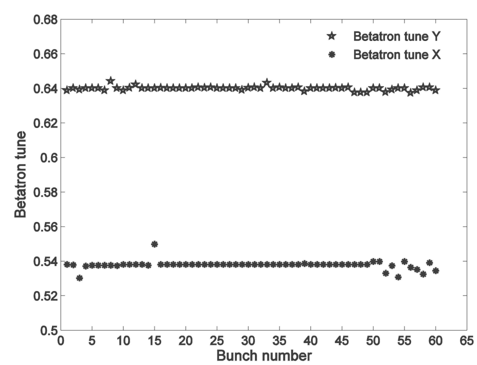

Fig. 2. Betatron tune along the bunch train.

4 Suppression on ECI in BEPCⅡ

Several measures including solenoid coils, larger chromaticity, octupole magnet and transverse feedback system, were adopted on the BEPCⅡ storage ring to control the ECI in the experiments.

Solenoid coils, powered by DC current, were verified to suppress the bunch size blow-up due to the ECI very effectively in both PEP-Ⅱ, KEKB low energy rings and BEPC[5—7]. In order to study the properties of ECI in the presence of solenoid coils, we wound as many solenoids as possible on the vacuum chamber of the straight sections around the BEPCⅡ storage ring. The total covered longitudinal length was about 35 m, occupying about 15% of the circumference of the ring. The magnetic strength of solenoid coils was about 30 Gs at a powering current of 30 A with four DC power supplies. Fig. 3 shows a fraction of the solenoids wounded in the BEPCⅡ storage ring.

The simulation shows that with 30 Gs solenoid magnetic field the electron density can be reduced by more than two orders. This effect can be explained that in the solenoid magnetic field, when the photo-electrons are produced on the pipe wall, the cyclotron motion occurs in the longitudinal magnetic field. So the electrons only accumulate in the vicinity of the pipe wall and the central density of the electron cloud can be reduced. All these results will be tested in the next experiments.

The larger positive Chromaticity can be effective to restrain the electron cloud instability which has been validated in the experiments of BEPC. In BEPCⅡ there are 9 sextupoles in each arc region. With these sextupoles, chromaticities of the BEPCⅡ storage ring are corrected to 1.0 in transverse. The larger chromaticity can be used for reducing the ECI, so the chromaticity used in the operation is decided by the dynamic aperture. In the experiments the chromaticity was changed from -4 to $+4$, the amplitude of sidebands was not reduced correspondingly. So its effect to suppress the ECI needs further investigation.

The Landau damping caused by the octupole is an effective way to restrain the coupled bunch instability caused by the electron cloud[7]. The octupole magnet has been installed in BEPCⅡ. The vertical sidebands of ECI disappeared when a DC current of 0.7 A, which corresponds to the integral field strength of 665 Gs/cm^2 of the octupole, was applied to the magnet. Fig. 4 shows the results of measurements.

The active transverse feedback system is an effective suppression for the coupled bunch instability caused by the electron cloud. The simulation shows that the growth time of ECI is about 0.5 ms[8], so the designed feedback damping time is set to 0.5 ms in the transverse direction. In the experiments the BPR was injected 93 bunches with a bunch spacing of 8 ns, and then we turned on and off the feedback to record the modification of the sideband. Fig. 5 shows the experimental results.

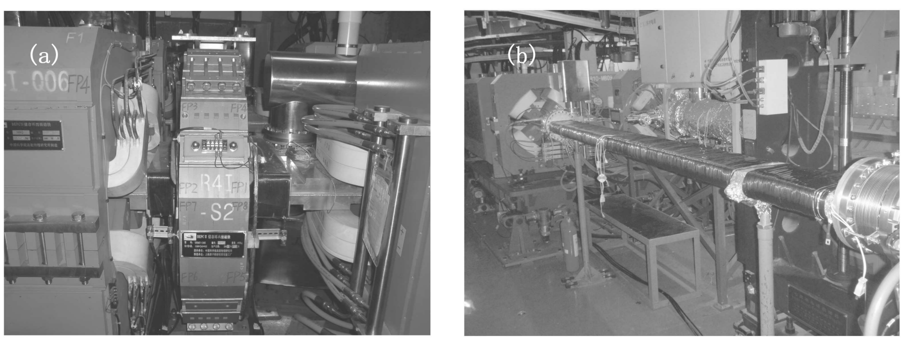

Fig. 3. Solenoids in BEPCⅡ. (a: the solenoid in arc region; b: the solenoid in long drift region).

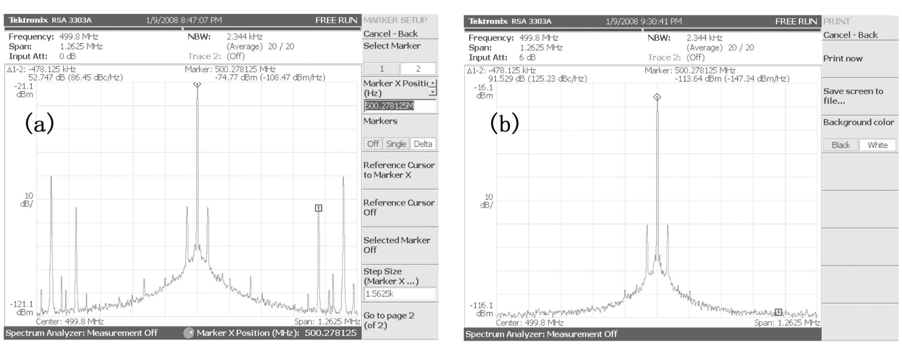

Fig. 4. Octupole effect to sideband amplitude. (a: without octupole current; b: with octuple current 0.7 A).

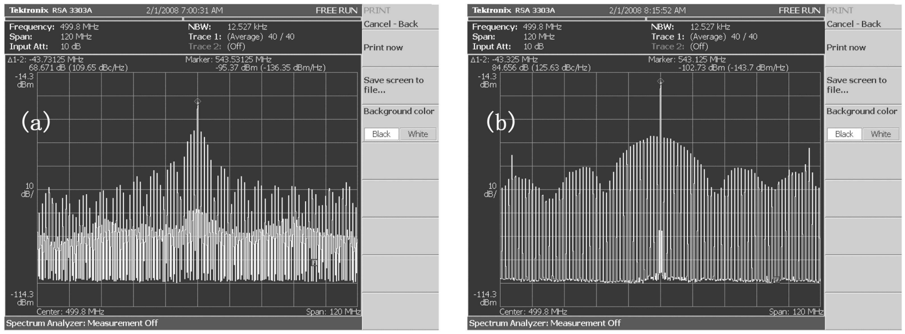

Fig. 5. Feedback system effect to sideband. (a: feedback off; b: feedback on).

It is obvious that when the feedback is on almost all the sidebands disappeared. That means all the coupled bunch instabilities were suppressed including the ECI. It is verified that the transverse feedback system can be an effective restriction to ECI.

5 Summary

Based on the ECI experiments in BEPCⅡ, the coupled bunch instability caused by the electron cloud has been observed obviously and the bunch size blow-up has not happened with the positron beam current 500 mA below. The following suppression methods of solenoids, octupole and transverse feedback system have been confirmed to be effective in the experimental studies. But the operation beam current is just half of the designed value (930 mA) and for guarantee the beam performance to reach the design goal luminosity, some of the effects relating to this instability are still needed further investigation, and further test in the experiment and machine operation.

We thank the BEPC operation team, instrumentation group and vacuum group for their support to the experiments, our special thanks go to Dr. Qin, Z. Zhao and H. Huang for their effective work in the experiments. Many discussions with Dr. K. Ohmi and H. Fukuma from KEK are very helpful to the study.

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