

BEAM INSTABILITY STUDIES OF BEPC AND BEPCII*

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Abstract

BEPC has been well operated for more than 15 years, and it will be upgraded to a double ring electron positron collider in the existing tunnel, namely BEPCII. This paper describes the recent studies on beam instabilities for the improvement of BEPC performance as well as for BEPCII. The instabilities caused by impedance and two-stream effects are investigated. The experimental and simulation results are reported.

INTRODUCTION

The Beijing Electron-Positron Collider (BEPC) has been well operated for both high energy physics (HEP) and synchrotron radiation (SR) researches for more than 15 years since it was put into operation in 1989. Besides many achievements in the τ -charm physics and SR applications, continuous efforts were made to improve the performance of accelerators. Last year the upgrade scheme from BEPC, called the BEPCII, was approved to improve luminosity for 2 orders [1]. BEPCII is a double-ring collider built in the existing BEPC tunnel while keeps the function as synchrotron radiation source. Its beam physics issues have been intensively studied [2]. Concerning to the collective effects, besides theoretic investigation, some experiment were done on BEPC to deepen the understanding and get practical experiences for BEPCII. This paper describes the recent studies on beam instabilities for the improvement of BEPC performance as well as for BEPCII. First the experimental studies in BEPC are described including the impedance related instabilities, which on the other hand are expressed as beam-based impedance measurement, and the electron cloud instabilities (ECI). Then the progress on collective effects study of BEPCII is introduced with focus on the ECI. A summary is given at last.

EXPERIMENTAL STUDIES ON BEPC

Since the BEPC was put into operation, many collective beam phenomena have been observed and studied [3], and the machine studies in recent years are mainly for better understanding the beam physics, paving the way to improve the performance and for the upgrade project, BEPCII. The studies include beam based impedance measurement, beam lifetime investigation and the ECI experiments.

Beam Based Impedance Studies

The coupling impedance is one of the most important issues affecting the performance of the beam. Particularly,

the single bunch current in BEPC as well as BEPCII is relatively large and the bunch length was once the key limit to the luminosity upgrade of BEPC, so much attention was paid to study the longitudinal impedance and bunch lengthening. These experiences are also beneficial to BEPCII.

The impedance of the storage ring has been estimated through the bench measurement of the main vacuum components [4], as well as numerical calculation [5]. Meantime, focus is on developing the beam based methods to determine the impedance, such as measurement on longitudinal bunch profile variation versus current, the synchrotron phase versus current, and the transverse tune versus current.

The bunch length and longitudinal bunch distribution was measured with both bunch spectrum and streak camera, then the scaling law is concluded, which reflects the longitudinal impedance. To obtain a practical impedance model, the longitudinal bunch distribution at low and medium current, which is assumed below the threshold of microwave instability, was fitted to asymmetric Gaussian distribution to get the resistive and inductive parts of the impedance model, respectively, the details can refer to [6].

The synchronous phase is determined by the beam energy balance between its gain from the RF voltage and its loss due to the synchrotron radiation plus the resistive impedance of the vacuum chamber. The latter part is called parasitic loss and can be represented by the loss factor, $k_l(\sigma)$, which depends on the bunch length σ . The parasitic loss is proportional to the bunch current and is compensated by an appropriate shift in the synchronous phase, $\Delta\varphi_s$, which is given by

$$V_{RF} \sin(\varphi_{s0} + \Delta\varphi_s) = \frac{U_0}{e} + k_l(\sigma)T_0I_b, \quad (1)$$

where, V_{RF} is the RF cavity voltage, φ_{s0} the synchronous phase at very low beam current, I_b the bunch current, T_0 the revolution frequency, U_0 the energy loss due to synchrotron radiation per turn. In the case that the $\Delta\varphi_s$ is small, the loss factor can be obtained as,

$$k_l(\sigma) = \frac{V_{rf} \cos \varphi_{s0}}{T_0} \frac{\Delta\varphi_s}{I_b}. \quad (2)$$

To measure the synchronous phase shift versus the bunch current, we injected two bunches into the storage ring. One bunch was kept as small as 1mA and taken as the phase reference, while increase the current in the other bunch. A Hamamatsu C5680 streak camera fitted with an M5679 dual time base extender unit and an M5675 is used to measure the longitudinal position of the two bunches. When the horizontal scan time sets at 1 μ s, the two bunches can be recorded on one snapshot by each

* Work supported by the Chinese National Foundation of Natural Sciences, contract 10275079 and 10375076

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horizontal scan. From the longitudinal distribution of the two bunches obtained from the vertical scan data, the centres of two bunches and the bunch length can be derived. The variation of the distance between the two bunch centres reflects the RF phase drift for compensating the parasitic loss due to the current increase of one of two bunches. The bunch length of the latter bunch is obtained by fitting with Gaussian distribution at the same time. Thus the loss factor of the BEPC storage ring is obtained as a function of the bunch length, shown as Fig. 1. At the bunch length of 4 cm, the loss factor is about 3.8V/pC, which is comparable with that got from the bunch length measurement [6].

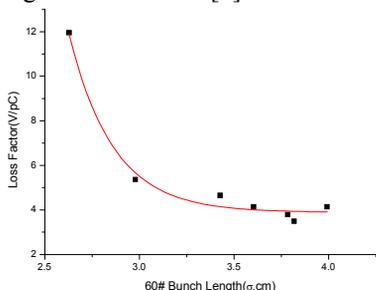


Figure 1: Loss factor versus the bunch length (the experimental dot and the fitting curve).

The transverse coupling impedance can be determined by the transverse tune shift versus the beam current,

$$\frac{\Delta \nu}{I_b} = \frac{R < \beta > Z_{eff}^{\perp}}{4\sqrt{\pi\sigma} E/e} \quad (3)$$

where Z_{eff}^{\perp} is the transverse effective impedance, R the average radius of the ring, $< \beta >$ the average beta function, E the beam energy. The longitudinal impedance can be got through relation,

$$Z_{\perp}(\omega) = \frac{2R}{b^2} \left| \frac{Z_{\parallel}}{n} \right|, \quad (4)$$

where b is the equivalent radius of beam tube, we take $b=0.03m$.

Measurement shows that the slop of the vertical tune to the bunch current is larger than the horizontal one. This is due to the beam pipe has smaller vertical dimension. In recent experiment, at 1.3GeV, the measured $\Delta \nu_y/I_b$ is about 0.00011/mA, corresponding to $Z_{eff}^{\perp} \sim 0.27 \text{ M}\Omega/m$ and $Z/n \sim 3.2\Omega$, which is comparable with the previous measurement of 4Ω [3]. In 2002, an in-vacuum wiggler, called 4W2, was installed in the storage ring to generate synchrotron radiation in hard x-rays and its vertical gap between magnet poles can be closed to the minimal of 15mm. We investigated the contribution to impedance due to the small gap at the operation energy of 2.2GeV. The vertical tune vs current was measured in the case with the 4W2 gap opened to 120mm and closed to 20mm, respectively. The data is shown as Fig. 2 and the results are: at gap=20mm, $\Delta \nu_y/I_b \sim 0.00008/mA$; at gap=120mm, $\Delta \nu_y/I_b \sim 0.00007/mA$. The difference on the tune itself in

two cases is due to the different status of another electric powered wiggler, 4W1, in the ring, which has focusing fringe field in vertical plane.

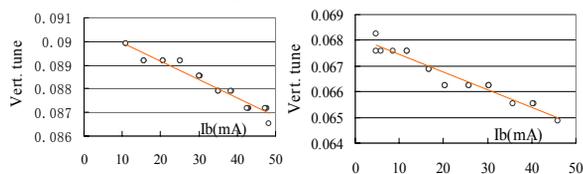


Figure 2: Measured tune shift vs bunch current (the experimental dots and the linear fitting curve; left: gap=20mm; right: gap=120mm).

According to the measurement results, though the length of 4W2 is only about 2 meters, which occupies about 1% of the ring, its contribution to the transverse impedance is more than 10%. And the smaller the gap is, the larger the contribution to impedance. In fact, this has been one factor affecting the beam performance when the gap of 4W2 is closed to less than 20mm.

For synchrotron radiation users with multi-bunch operation, the beam lifetime is about 20 hours at 130mA when 4W2 is open to its full gap of 120mm. However, the beam lifetime reduced to only about 6 hours at 130mA when 4W2 gap was closed to 20mm, though a series experiment was done on tuning the coupling and orbit. Considering that the resistive wall impedance increases when the gap decreases and the according instabilities may lead to more beam loss. We decided to adjust the ν_x/ν_y from 8.75/4.75, which are above half integer, to 9.38/5.14 which above integer to alleviate the instability. This worked and the gap was been able to be closed to 18mm with beam lifetime of 8 hours at 130mA. Tuning ν_y to 5.10 shows longer lifetime and more stable beam with the vertical betatron sidebands disappeared. Further experiments such as to minimize β_y at 4W2 to improve the beam performance with smaller gap are planned.

Electron Cloud Instability (ECI)

Since 1996, ECI has been studied systematically with experiments [7]. To develop the cure methods on ECI for BEPCII, from last year, we did some experiments with the solenoid winding, the clearing electrode, and the octupoles. The details were described in [8]. Here we just list several results from the experiment, which were verified effective and give us insight for BEPCII.

1) When solenoid is powered with current of 15A, the sidebands of vertical coupled bunch instability is suppressed and the vertical bunch size in the tail of bunch train is reduced about 15% in average.

2) Clearing electrode decreases the EC detected, and it is feasible to put voltage on the button of BPMs serving as clearing electrode. The amplitudes of sidebands reduced about 20% with voltage of 600V on BPMs.

3) When octupole is powered on, the sidebands of coupled bunch instability is suppressed and the bunch size of the tail bunch is reduced about 20%.

4) Larger chromaticity is helpful to cure both single and coupled bunch instabilities.

INSTABILITIES IN BEPCII

Since the single beam current in BEPCII design gets to 910 mA with the single bunch current of 9.8 mA, both the single and multi-bunch effects will influence the performance of the beam. To control instabilities due to impedance and the two-stream effects is one key issue of physics design. Concerning to the impedance, in order to realize the micro- β scheme for high luminosity, a strict impedance budget has been made in order to control the bunch lengthening with efforts on designing the beam pipe as smooth as possible. A budget of $(Z/n)_0$ has been made as 0.23Ω with numerical calculation [9]. Recently a platform for bench measurement of impedance was set up in collaboration with Tsinghua University. Then the impedance of manufactured prototypes can be checked with measurement. For the collective effects, the growth rate of coupled bunch instabilities was estimated with analytical formula [10] and confirmed with multi-tracking study. As conclusion, bunch to bunch feedback system is required to damp the multi-bunch instabilities. Since ECI can be the most severe hindrance to the luminosity performance as that was found and finally cured with enormous effects in KEKB and PEP-II, our recent study of beam instabilities in BEPCII also emphasizes on ECI.

To guarantee the beam performance against ECI, antechamber with TiN coating is decided to be used in the arc to reduce the primary and secondary electron yields. To evaluate the ECI practically, a simulation code [11] has been developed to estimate the electron cloud density taking into account each effect due to the antechamber structure, the TiN coating and clearing electrode, respectively. The coupled bunch instability and the beam blow up as the head-tail model are also studied with the code. A typical distribution of electron cloud density in the antechamber is shown in Fig.3.

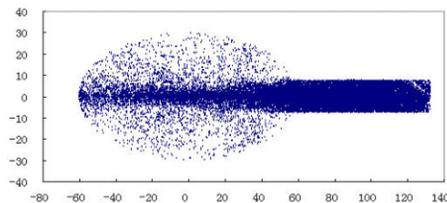


Figure 3: The electron cloud density in the antechamber.

Simulation results show that the EC density can be reduced by about 5 times if the antechamber is adopted, by about 6 times if the TiN is coated only, by about 3 times if the photon absorber is made in the wall of the chamber only, by about 5 times if the electrode is installed in the beam chamber. So in BEPCII the electron density will be decreased about 90 times, i.e., from $1.1 \times 10^{13} \text{ m}^{-3}$ in the case without any restraining method to $1.3 \times 10^{11} \text{ m}^{-3}$, which is lower than the threshold causing the strong head-tail instability as described later.

The single bunch blow up is simulated based on the head tail model [12]. Tracking the bunch for 4096 turns with different EC density, we found that the vertical bunch size increases sharply when the EC density is

higher than $9.2 \times 10^{11} \text{ m}^{-3}$, which can be thought as the instability threshold, shown in Fig. 4. So the EC in BEPCII with antechamber can be lower than the threshold. If the chromaticity is introduced in the simulation, the growth of bunch size becomes saturated and the larger the chromaticity, the stronger the damping effect. This result is compared with the observation on BEPC.

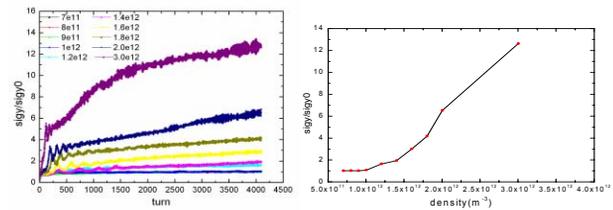


Figure 4: Bunch size vs different EC density.

To study the coupled bunch instability, the motion of 93 bunches in a train is recorded in each turn in addition to the simulation of the build up process of EC density. The growth time is obtained by fitting the amplitude of the oscillation, and the coupled bunch mode can be got by FFT of the data. For BEPCII with antechamber and TiN coating adopted, the EC density will be decreased to $1.3 \times 10^{11} \text{ m}^{-3}$. The growth time of coupled bunch instability is about 4.3 ms which can be damped with feedback system.

SUMMARY

The study of beam instabilities has been progressing in BEPC for years, and quite rich study results have been obtained. The beam based impedance measurement and the ECI study not only deepen the understanding of the collective beam phenomena in BEPC, but also provide experience for future studies in BEPCII. Concerning the beam instabilities in BEPCII, there are no showstoppers affecting the designed performance, and further study is still under way.

ACKNOWLEDGMENTS

We thank the BEPC operation team, instrumentation and vacuum groups for their supports to the experiments.

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