SINGLE BEAM PHENOMENA IN BEPC

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Abstract

Beijing Electron Positron Collider (BEPC) is operated as a colliding beam facility as well as a synchrotron radiation source. The maximum single bunch beam currents of 85mA and the maximum multibunch beam currents of 150mA are reached which are stronger than the designed goal[1]. In this paper the dependence of BEPC single beam phenomena on the beam current and the single beam instabilities are described; the beam current limitations are discussed and the single beam phenomena are analysed.

I. INTRODUCTION

BEPC has been operating stably since the first e^-e^+ collision in 1988. The injection energy is 1.3 GeV for the 2.015 GeV colliding and the 2.2 GeV dedicated synchrotron radiation research at the present operation. No serious beam instability has been observed in BEPC at the present operation level which is attributed to the efforts of making the coupling impedance well controlled. The colliding beam current limit is due to the beam-beam interaction[2]. As for the synchrotron radiation operation, the limitation is from the RF power that the cavity ceramic windows permit.

Many interesting phenomena are observed, including the bunch lengthening, the energy spread widening, the transverse beam blow up, the tune shift, the head tail instability, the beam-cavity interaction, the longitudinal coherent oscillation and the multibunch effects.

II. COUPLING IMPEDANCE

The coupling impedance expresses the interaction between the beam and the environments. It is a key parameter for the single beam instabilities.

At the beginning of the BEPC construction, we have paid more attentions to making the vacuum chamber as smooth as possible, to reducing the angle of the taper smaller where the dimension of the vacuum chamber is changed, to using two levers bellow to expand the wave length, to designing the injection kickers and the vacuum gates carefully and to forming the flange gaps more narrow and shallow. All of these considerations result in a quite small coupling impedance. For every component, the coupling impedance was estimated by means of the computer code TBCI and UMREL or estimated semi-analytically. During the machine building, the coupling impedance of some typical components such as RF cavities, kickers, bellows, tapers, flanges are measured by the simulation current method[3]. The whole machine coupling impedance is also determined by measuring the tune shifts as a function of beam current, which is in the form of:

$$\frac{\Delta Q}{I} = -\left(\frac{eR^2 R_T}{2QE}\right)F(\sigma_l)$$

Q is the tune and I, E are the beam current and energy respectively. R_T implies the impedance and $F(\sigma_l)$ is a function of the bunch length. R is the average radius of the storage ring. So the impedance can be easily deduced and it is quite in accord with other methods. The averaged impedance obtained above is: $|Z/n|_0 = 4.0\Omega$.

III. CURRENT DEPENDENT PHENOMENA

A. Bunch Lengthening

The bunch lengthening is one of the most important issues in electron positron collider for the bunch length would influence the achievable luminosity, which could be observed in BEPC[4].

This phenomenon is explained with two sorts of theories, i.e. potential well distortion and longitudinal turbulence instability. When the beam currents are over certain value, the stronger bunch lengthening as well as the energy widening increases with it. The bunch lengthening effect has been measured in BEPC with the different methods: the synchrotron light monitor and the wall current monitor. The scaling law for the bunch lengthening[5] predicts that the bunch length is a function as follows:

$$\sigma_l = a\left(\frac{I\alpha_p}{E\nu_s^2}\right)^b$$

where a and b are constant for a certain machine. The bunch lengthes are measured under the different conditions ν_s, I, E, and α_p and the preliminary parameters a and b are obtained for BEPC. The rms bunch length is about 5~10cm. The threshold of turbulence is about 8~10 mA at 1.55 GeV. The measurement errors are caused by the instrument rising time and non-gaussian form of the beam. For the accurate measurement of the bunch length, several methods are being studied under way.

B. Energy Spread Widening

The energy spread increases above a current threshold. It is measured by limiting the longitudinal bucket acceptance[6] via decreasing the RF voltage until the quantum life time becomes dominant in BEPC. Therefore it can be carried out by measuring the synchrotron frequency and beam life time. The results at 1.7724 GeV are shown in Fig.1. It is obvious that the energy spread widening begins at 8~10mA, which is quite in agreement with the bunch

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lengthening measurements and the results detector people obtained in τ mass determination experiments.

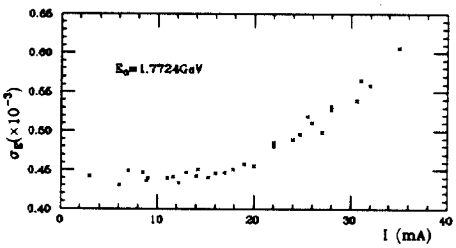

Fig.1 Energy Spread Measurements

C. Transverse Beam Blow-up

The transverse beam blow up is a very important subject especially to BEPC upgrade plans[7]. The scraper was applied to reduce the beam life time to the transverse quantum life time and therefore the beam sizes σ_x, σ_y can be found. The emittance and the transverse coupling at different energy and different currents have been measured, which are shown in Fig.2. The horizontal beam emittance is proportional to γ^2 as the theory predicted but the vertical beam emittance is almost unchanged with energy. At least 20% increment of the beam emittance occurs if the beam reaches 50mA.

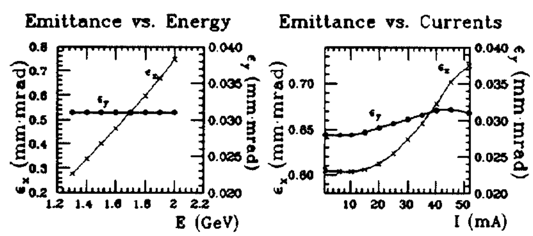

Fig.2 Emittance Measurements

D. Tune Shift

The theory of the single beam effects predicts that the tune will be changed when the beam gets stronger. The measured betatron and the synchrotron frequency as functions of the beam current[8] are showed in Fig.3.

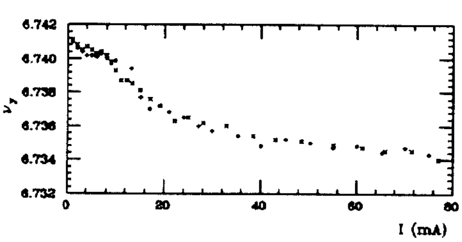

Fig.3 Tune Shift Measurements

The signal is picked up from a monitor with four strip lines. The observation shows that the vertical tune decreases with the beam current in a slope of -0.00025/mA at 1.3 GeV first, then with a much smaller slope later above 20 mA. The horizontal tune and the synchrotron tune changes slightly with the beam current.

IV. SINGLE BEAM INSTABILITIES

A. Head Tail Instability

The basic theory of this transverse instability is well understood and the phenomenon is observed in many accelerators. The beam current threshold is less than 1mA. The lower mode of the head-tail instability is overcome when the chromaticity is corrected to 0.5 . At the normal operating condition we choose it as 2 or 3 by four families of sextupole. The chromaticity is set to 4 or 5 to avoid the beam loss during the energy ramping, detuning and separators turning off.

B. Beam-cavity Interaction

There are two 200MHz RF cavities in BEPC storage ring and two more RF cavities will be installed in the ring for enhancing the RF voltage to shorten the bunch length. Higher order modes can be excited in the cavity. The parameters of the higher order mode have been calculated by the computer program URMEL and compared with the measurement results. The beam could be unstable if the tuner of the idle RF cavity is not put into the correct position. The observation on Robinson effect in BEPC is identical with the theory. The detuning angle of the RF cavity is controlled by tuning loop in normal operation to damp it and the similar effects from the higher order mode and the frequency variation influenced by temperature.

C. Longitudinal Coherent Oscillation

The longitudinal coherent oscillation could be excited in a bunched beam[9], caused by some noises especially in the RF system. The signals of the oscillations can be observed on the wall current monitor and the spectrum analyser, and also can be picked up from the strip line monitor shown in Fig.4.

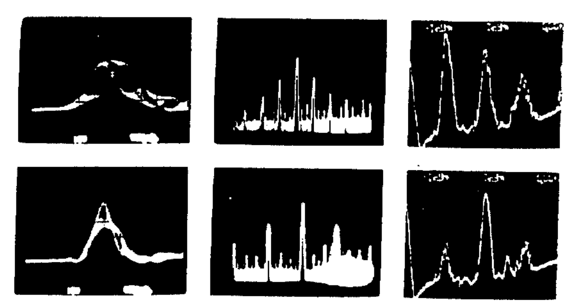

Fig.4 Longitudinal Signal Spectrum

The normal luminosity records are shown in Fig.5a. Occasionally the luminosity decreases during a short period and then returns to the normal level as shown in Fig.5b. When the oscillation occurs, the beam life time decreases slightly and the significant signal of the longitudinal coherent oscillations especially the dipole mode can be found in three kinds of monitor as mentioned above. The luminosity decreases about 20% usually and the amplitude of the dipole mode oscillation can be estimated about 3° from the signal on the wall current monitor.

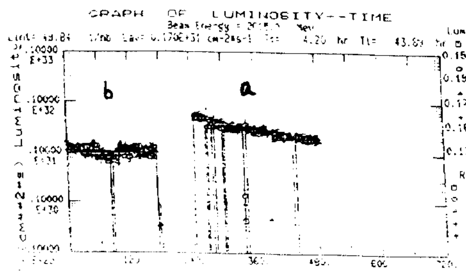

Fig.5 Luminosity Records

When both the electron bunch and positron bunch execute the longitudinal dipole coherent oscillations, there are two possible phases, i.e. in phase or out of phase. If they are in phase, which means the electron bunch and the positron bunch arrive at the designed interaction point in the same time because they advance or delay in the same manner. But in the out of phase oscillation case, the real interaction point of two bunches alternates around the designed interaction point with the same amplitude and the same frequency of the dipole longitudinal oscillation. Because the β function and the transverse beam size are minimized at the designed interaction point, the luminosity should be decreased if the real interaction point deviates from the designed one. In the higher mode cases m=2, 3, 4,$\cdots$, the real interaction point does not move from the designed point, but the bunch length will be disturbed and oscillated in the different modes at the different harmonics.

A detail analysis of the luminosity decreasing from the longitudinal coherent oscillation has been done[10]. The integrated effects of any order longitudinal coherent oscillation have been calculated. For the typical measured parameters of these oscillation, about 15% of the luminosity decrement comes from the dipole mode, 2% from the quadrupole mode, and 2% or 3% from the sum of other higher order modes. This is coincident with the luminosity observation and measurement. Hence the longitudinal feedback system is being developed for damping the dipole mode oscillation.

D. Multibunch Instability

There are 160 RF buckets in which particles can be filled. Multibunch mode is operated for synchrotron radiation research dedicatedly. The multibunch instabilities are driven by narrow band impedance i.e. high order resonantors, such as the high order eigenmodes in the RF cavities or in the cavity like objects. The different filling patterns were tried in BEPC and the multibunch instabilities have been found. The possible multibunch patterns are shown in Fig.6. The results exhibit that the more bunches are, the less particles can be filled in each bucket; the farther distance between the bunches the more particles will be filled in each bunch; it is better that the distances between adjacent bunch are the same and the preferable patterns are 4 or 8 bunches distributed uniformly.

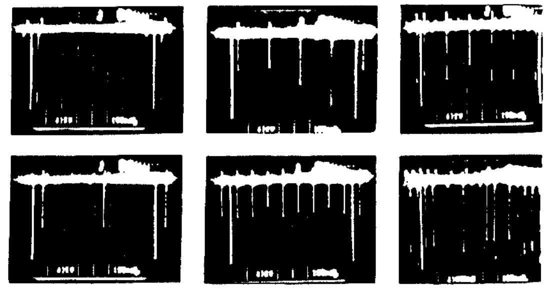

Fig.6 Multibunch Patterns

V. CONCLUSION

Many interesting phenomena have been observed in BEPC. For future luminosity upgrade plans, stronger beam currents are desired and some limitation for the higher luminosity might be come from the single beam effects such as the bunch lengthening, the beam transverse blow up, the energy spread widening and other instabilities. Much more RF power and higher RF voltage are required for adding other two RF cavities to store stronger beam and to suppress the bunch length. The longitudinal feedback system has to be set up effectively for keeping the integrated luminosity at the highest level.

VI. ACKNOWLEDGEMENT

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VIII. REFERENCES

[1] BEPC Group, *15th Int. Conf. on High Energy Acc.* (1992)

[2] BEPC AP Group, *5th Chinese Acc. Conf.* (1992)

[3] G.W. Wang, Ph.D. Thesis (1989)

[4] L. Ma, *Proc. of the BEPC Workshop* (1984)

[5] A. Chao et al., *IEEE Trans. Nucl. Sci.* , **NS-24** (1977)

[6] X.L. Zhang et al., BEPC-AP/MD 92-06 (1992)

[7] C. Zhang, *BEPC Upgrades Plans*

[8] G.X. Li et al., BEPC-AP/MD 92-08 (1992)

[9] B. Zotter and F. Sacherer, CERN 77-13

[10] Z.Y. Guo, *5th Chinese Acc. Conf. (1992)*