STUDIES ON THE BEAM CURRENT DEPENDENT PHENOMENA IN THE BEPC-II STORAGE RINGS*

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Abstract

The commissioning of the upgrade project of the Beijing Electron Positron Collider (BEPCII) started on Nov. 12, 2006. During the 1st and 2nd stages of the commissioning of the BEPCII rings, we had got the luminosity one tenth of its design value, provided beams to synchrotron radiation users for ~ 4 months, and studied beam dynamics as well. In this paper, some preliminary results of the beam dynamics will be given.

INTRODUCTION

The upgrade project of the Beijing Electron Positron Collider (BEPC), BEPCII, is mainly composed of a linac, two transport lines and two storage rings in parallel for e- and e+ beams, respectively. The two halves of the outer rings are connected as a synchrotron radiation (SR) ring, with 14 beam lines extracted from 5 wigglers and 9 bending magnets. The layout and other details of the three rings of BEPCII can be found in [1].

In this paper, we mainly discuss some beam current dependent phenomena in the collision rings, say, BER and BPR for e- and e+ beams, respectively. Some main nominal parameters of the lattice are listed in Table 1.

Table 1: Main parameters of the BEPCII collision rings

Beam energy	GeV	1.89
Circumference	m	237.53
Beam current	A	0.91
Bunch current / Bunch No.	mA	9.8 / 93
Natural bunch length	mm	13.6
RF frequency	MHz	499.8
Harmonic number		396
Emittance (x/y)	nm.rad	144/2.2
β function at IP (x/y)	m	1.0/0.015
Crossing angle	mrad	$\pm$11
Tune (x/y/s)		6.54/5.59/0.034
Momentum compaction		0.0237
Energy spread		5.16×10^{-4}
Natural chromaticity (x/y)		–10.8/–20.8
Luminosity	$cm^{-2}s^{-1}$	1×10^{33}

Both BER and BPR have same magnetic lattices with the super period number of 1. Figure 1 shows the Twiss functions in the interaction region, the RF region and the whole ring. In order to have a big emittance and a high beam current, a quasi-FODO structure with 10 dipoles and 2 missing dipoles in each arc is applied.

In the second section, we will discuss the single bunch beam dynamics studies. Multi-bunch beam effects will be introduced in section 3. Some instabilities were observed and showed in section 4. At last, a summary will be given.

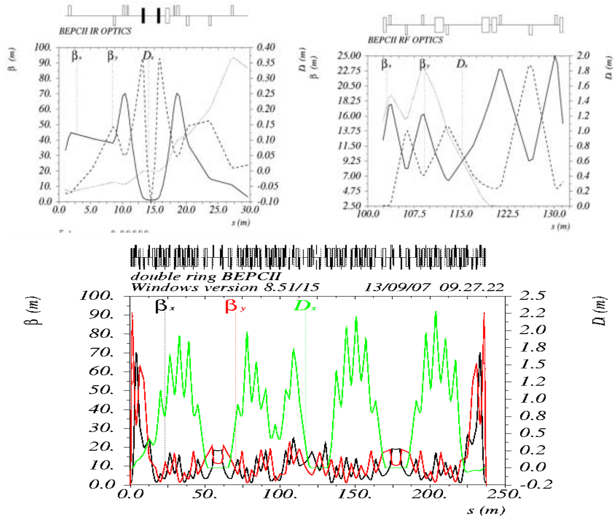

Figure 1: Twiss functions in the IR (up-left), the RF region (up-right) and the whole ring (down) of BER/BPR

SINGLE BUNCH BEAM DYNAMICS

Optics correction

After beams were injected smoothly into the rings, the β functions along the rings are measured before and after the optics corrections based on the measured response matrices [2]. The relative errors between the nominal and measured beta functions are less then 10% averagely. Other Twiss functions, such as dispersions and transverse tunes, were also measured and close to the design values. Under these circumstances, we could do some beam observations and measurements of other parameter.

Beam energy spread

Beam energy spread was measured with the method of longitudinal quantum lifetime. If the RF voltage is set to keep a relatively short beam lifetime, say 20 or 30 min, thus the longitudinal quantum lifetime can be considered as the dominant one. The beam energy spread at different bunch current could be estimated with the longitudinal momentum acceptance. Figure 2 shows the beam energy spreads at different bunch current in both BER and BPR.

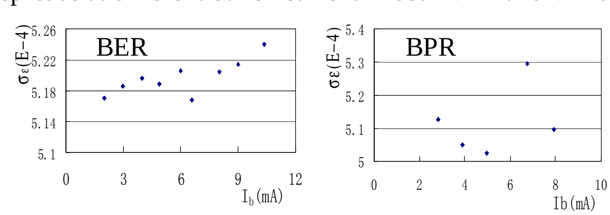

Figure 2: Beam energy spread vs. bunch current

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The average beam energy spread of the two rings could be then got as 5.20×10^{-4} for BER and 5.12×10^{-4} for BPR.

Bunch Lengthening

Bunch lengthening is one of the main reasons which limit the luminosity in collider. We measured the bunch lengthening in both rings with streak camera after the lattice correction. Single bunch was used for each beam without collision in the measurement. With the calibrated RF voltage and the measured synchrotron tune, the momentum compaction was calculated. The bunch length is fitted with the distribution of bi-Gaussian as that used in the BEPC before [3]. Static image was measured and reduced from the measured bunch lengths. Figure 3 shows the bunch lengthening as a function of bunch current in the BER and BPR, respectively.

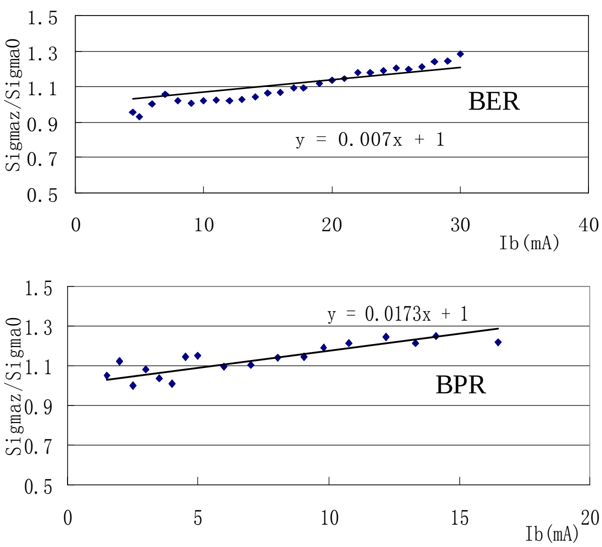

Figure 3: Bunch lengthening vs. bunch current

From the bunch lengthening, we can get the inductance of the BER and BPR as L = 32.1 nH and L = 118 nH, respectively, which correspond to $|Z/n|_0$ = 0.25 Ω and $|Z/n|_0$ = 0.94 Ω. Since the bunch lengthens at low current due to potential well distortion, it can be expressed as [4]

$$\frac{\sigma_l}{\sigma_{l0}} \approx 1+\frac{e\alpha_p I_b \omega_0 L}{8\sqrt{\pi}\nu_s^2 E}\left(\frac{R}{\sigma_{l0}}\right)^3, \tag{1}$$

where σ_l and σ_{l0} are the bunch length at current I_b and the natural bunch length, respectively, α_p the momentum compaction, ω_0 the angular revolutionary frequency, L the inductance, R the average radius of ring, ν_s the longitudinal tune, and E the beam energy. With the calculated L from the bunch lengthening measurement, we can get $\sigma_l/\sigma_{l0} \approx 0.0053I_b$+1 for the BER and $\sigma_l/\sigma_{l0} \approx 0.01855I_b$+1 for the BPR, respectively, which are similar with the fitting results shown in Fig. 3.

Tune Variation as a Function of Bunch Current

The effective impedance can also be estimated from the tune variation due to the changing of bunch current with the following expressions [5]:

$$\frac{d\nu_\perp}{dI} = \frac{R}{4\sqrt{\pi}(E/e)\sigma_l}\bar{\beta}_\perp Z_{\perp,eff}\ , \tag{2}$$

where $\bar{\beta}_\perp$ is the average β function around the ring. Figure 4 shows transverse tunes as functions of bunch current in both rings. All the measurements are done without any collision, and the tunes are measured with the FFT done by the signals taken from the single pass BPM. With the eq. (1) and $|Z/n|_0=b^2Z_{\perp,eff}/2R$, the estimated low frequency longitudinal impedances of the BER and BPR are $|Z/n|_0$ = 1.29 Ω and $|Z/n|_0$ = 1.10 Ω, respectively. The errors of fitting are less than ±3% after data filtering.

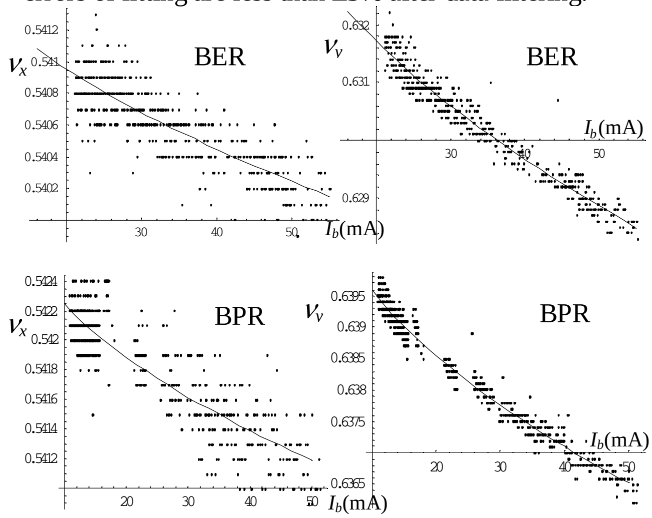

Figure 4: Tune variation as a function of bunch current.

Single bunch beam Lifetime

The single bunch beam lifetimes in the BER and BPR were measured for several times under different machine conditions, as shown in Fig. 5. The RF voltages are kept as 1.5 MV for enough longitudinal Touschek lifetime.

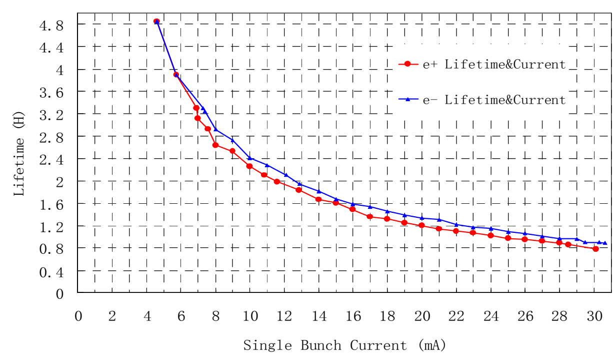

Figure 5: Single bunch beam lifetime observation

If we take the beam lifetime at low current as the Touschek lifetime, we can get 10 hrs@1mA for both rings by extrapolating the curves in Fig. 5. It is far from the design Touschek lifetime of 7.1 hrs@9.8mA. With the vacuum pressure given in the rings, the beam-gas lifetime can be estimated. The residual gas consists of about 70% CO and 30% H_2 in the BPR, and 30% CO and 70% H_2 in the BER. At the bunch current of 1 mA, the beam-gas lifetime of e+ beam is calculated as 146 hrs with the average vacuum pressure of 0.178 nTorr. So the total calculated lifetime of e+ beam is ~43 hrs, which is larger than 10 hrs we observed and hints that the vacuum is not as good as expected in both rings.

MULTI-BUNCH BEAM DYNAMICS

Multi-bunch beam lifetime

The beam lifetime of multi-bunch case is also observed with different beam currents and vacuum pressure. Figure 6 depicts the average vacuum pressure under different beam current in both rings. Taking an example of 500mA *500mA in collision for both beams, we have the average vacuum pressure of 3.58 nTorr in BPR and 1.79 nTorr in BER. The various beam lifetimes calculated in both rings and the observed lifetimes are listed in Table 3.

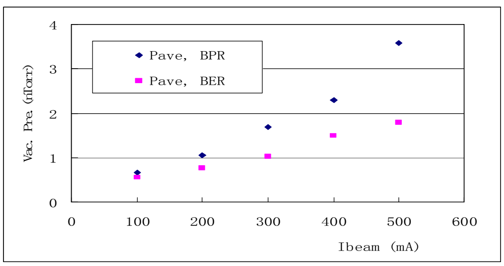

Figure 6: Average vacuum at different beam current

From Table 2, we can see that the e+ beam lifetime agrees very well to the observed one, while the e- beam doesn't. The reason should be the same as the single bunch case. It is believed that if the vacuum improved, the lifetime at very low bunch current should be longer, and the total beam lifetime would be longer too.

Table 2 Calculated and observed (obsd.) beam lifetime

	<*p*> (nTorr)	b-g (hr)	Tous. (hr)	b-b (hr)	Total (hr)	obsd. (hr)
BER	1.79	33	2.0	6.0	1.44	2.94
BPR	3.58	7.3	2.0	6.0	1.24	1.12

Electron cloud observations

The beam blow-up due to the electron cloud (EC) will cause the reduction of luminosity and the coupled bunch instability will limit the beam current. The electron cloud instability (ECI) was also observed clearly in the BPR, though the beam current is not very high. Figure 7 shows the beam spectra in both rings. In Fig. 7, the beam current is 40 mA in both rings with the same filling pattern. We can easily find that there're more sidebands in BPR than that in BER, which is one of the main evidences of ECI.

Keeping the same filling pattern but changing the bunch current, we can find the threshold beam current of ECI for different bunch numbers, as the example shown in Fig. 8. Table 3 summarizes the threshold we got in the experiment. It seems the threshold current of ECI is low, which is about two times higher than that in BEPC [6].

Table 3 Threshold beam current of ECI @different N_b&S_b

N_b	S_b (RF bucket)	I_b (mA)	I_{th} (mA)
48	8	~1.0	~50
99	4	~0.35	~35
198	2	~0.15	~30

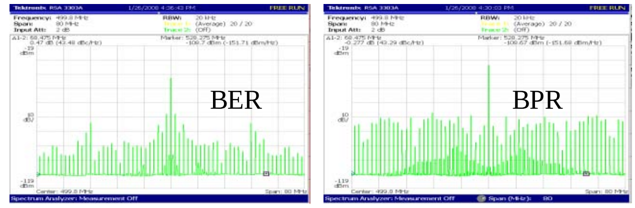

Figure 7: Spectrum distribution of both rings with same I_B

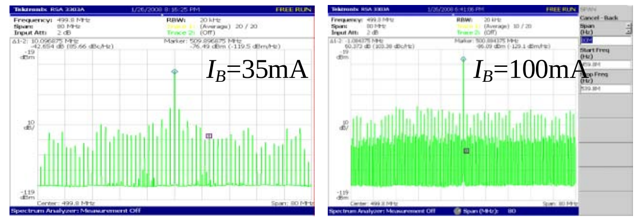

Figure 8: Spectrum in BPR (N_b = 99, uniform filling)

The mode distributions got from sidebands analysis are shown in Fig. 9, where we can easily find the difference between the BER and BPR. The power of BPR's betatron sidebands shown in Fig. 9 looks similar as that got from the BEPC [6], which is another evidence of ECI effect.

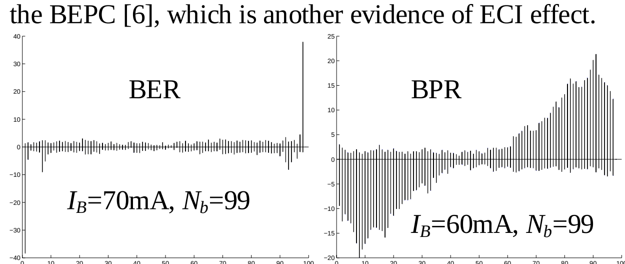

Figure 9: Mode distribution between BER and BPR

SUMMARY

The BEPCII rings reach their main design parameters after the optics correction in the commissioning. Twiss functions are measured along the rings, and close to the nominal values. Some current dependent phenomena were observed. Single bunch effects, such as bunch lengthening and tune variation reveal the impedance related issues, and the low frequency longitudinal impedances of the two rings are got. The measured Touschek beam lifetime is far from the calculated one, and thus the total beam lifetime does not agree well enough to the observed one. It could be explained somewhat that the vacuum is not as good as expected right now. ECI has been observed in the e+ ring of BEPCII. The spectra and mode distribution are studied under different bunch patter and current. The threshold current of ECI with 99 uniform filling bunches is about 35 mA. Further studies on beam phenomena are needed.

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