THE SECOND PHASE COMMISSIONING OF BEPCII

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Abstract

BEPCII is the upgrade project of Beijing Electron-Positron Collider (BEPC), which will operate in the beam energy region of 1-2.1 GeV with the design luminosity of 1×10^{33}cm^{-2}s^{-1} at 1.89 GeV. From Nov. 2006 to Aug. 2007, the phase one beam commissioning of BEPCII storage rings was carried out with the so called backup scheme which adopted conventional magnets in the IR instead of the superconducting insertion magnets (SIM). After the SIM was installed into the interaction region, the second phase commissioning began in Oct. 2007. The tuning method for high luminosity but low background has been extensively studied, and the beam current reached more than 1/2 of the design of 0.91 A, with the luminosity higher than 1×10^{32}cm^{-2}s^{-1}, which is 10 times of BEPC. In addition, beam was delivered to SR users for about 1 month at 2.5GeV with maximum current over 250mA. This paper describes the progress on beam commissioning, the main results achieved and issues related to high current and high luminosity.

INTRODUCTION

The BEPCII is the upgrade project of BEPC, serving continuously the dual purpose of high energy physics experiments and synchrotron radiation applications. The design goals and its construction is described in Ref. [1,2]. As an e^+-e^- collider, it consists of an electron ring (BER) and positron ring (BPR), respectively. The two rings cross each other at the southern interaction point (IP), where the dector is located, with a horizontal crossing angle of 11mrad×2. A pair of superconducting insertion magnets (SIM) are used to squeeze the β function at the IP, compensating the detector solenoid and to serve as the bridge connecting two outer half rings for SR operation, respectively. For the dedicated synchrotron radiation mode, electron beam circulates in the ring made up of two outer half rings. 5 wigglers were installed in the outer rings to generate more strong SR.

In accordance to the progress of construction, as well as to meet the demand from the SR users community, the beam commissioning of BEPCII is carried out in 3 phases: Phase 1, with the backup scheme which adopted the conventional magnets in the IR instead of SIM; Phase 2, with SIM in the IR; Phase 3, joint commissioning with detector.

The phase 1 commissioning was from Nov. 13, 2006 to Aug. 3, 2007. In this phase, 100mA by 100mA beam collision was achieved with β_y^*=5cm, while the estimated luminosity reached the level of BEPC. Two rounds of synchrotron radiation operation were arranged during the period. The beam performance and commissioning results have been reported on the APAC07 [3] and PAC07[4].

After the superconducting magnets SIM's and new vacuum chambers were installed into the IR in summer of 2007. The second phase commissioning was carried out from October 24, 2007 to Mar. 28, 2008. The main milestones of this phase of commissioning are listed in the following:

Oct. 25, the electron beam was stored

Oct. 31, the positron beam was stored

Nov. 18, the first e^+ e^- collision realized at β_y^*=1.5cm

Jan. 29, 2×500mA e^+ e^- collision realized with luminosity higher than 1×10^{32}cm^{-2}s^{-1}

In this phase, the dedicated SR mode was run for about one month, with peak beam current of 250mA. The beam lifetime reached to 10hrs at 200mA while the gap of the in-vacuum wiggler 4W2 was set to 18mm.

The following sections will mainly introduce the second phase commissioning for the collision mode, including the beam performance, the luminosity tuning and some issues relating to high beam current.

BEAM CURRENT GROWTH

The second phase commissioning of BER and BPR started in Oct. 2007. Since the difference on the storage ring between the first and second phases is only on the final focus quadrupoles, it took only one day to get beam stored in BER and BPR respectively.

To keep the vacuum pressure of the superconducting cavities well below the threshold set for the RF window protection, the rate to increase the beam currents in both rings was deliberately restrained to 10mA per day. However, when the beam current in BER exceeded 100mA,

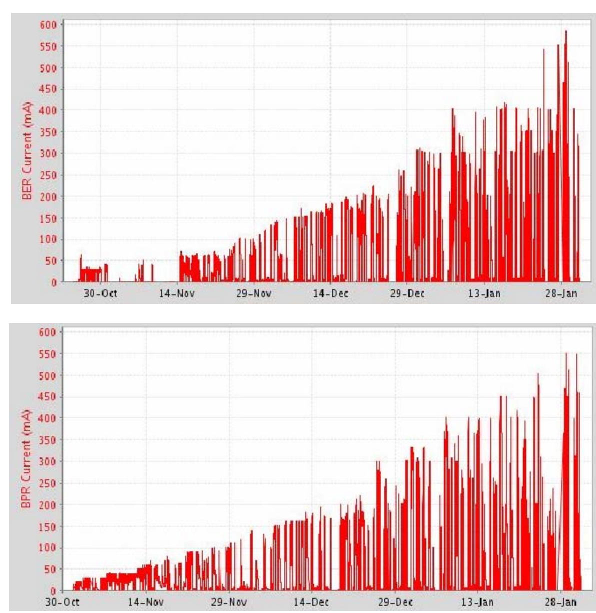

Figure 1: Current growth during the period of commissioning, BER (upper) and BPR (down)

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the SC cavity (SCC) tripped often due to its arc interlock of window and following vacuum pressure raised quickly.. Similar condition happened in BPR when the current is over 200mA. To overcome the problem, a DC bias voltage was used on the power coupler of the SC cavity to suppress the multipacting effect. This worked very effectively and the vacuum condition significantly improved. Then the beam current of both rings was able to be improved steadily. Transverse feedback system was employed for smooth injection and stable operation at high beam current. The growths of the beam current in the BER and BPR are shown in Fig. 1.

BEAM PERFORMANCE

Optics and orbit

Then closed orbit and optics correction was done based on the response matrix and its analysis using LOCO (Linear Optics from Closed Orbits) method [5]. As the result, the measured beam optics functions are in good agreement with theoretical prediction with discrepancy within ±10% at most quadrupoles [6]. Table 2 summarizes the main parameters achieved for BER and BPR during this commissioning period.

Table 1: The main parameters of the BER and BPR

Parameters	Design	Achieved	
		BER	BPR
Energy (GeV)	1.89	1.89	1.89
Beam curr. (mA)	910	550	550
Bunch curr. (mA)	9.8	>10	>10
Bunch number	93	93	93
RF voltage	1.5	1.6	1.6
Tunes (ν_x/ν_y)	6.54 /5.59	6.544 /5.599	6.540 /5.596
$*\nu_s$ @ V_{RF}= 1.5MV	0.033	0.032	0.032
β_x^*/β_y^* (m)	1.0 /0.015	~1.0 /0.016	~1.0 0.016
Inject. Rate (mA/min)	200 e^- 50 e^+	>200	>50

$*\nu_s$ is extrapolated from the measurement at RF voltage of 1.69 MV for BER and 1.61MV for BPR, respectively.

LOCO analysis indicated that the quadrupole strengths are mostly lower than the design set within 1~2%. One contribution to this systemic component was from the short distance between the quadrupole and its adjacent sextupole. Another may from the fringe filed effect. Other origin of these errors is still pursued.

Injection

Efforts were mainly paid to improve the injection rate of positron beam. After the optimization of energy set and the orbit in the transport line, the injection rate was improved to more than 50mA/min, which is the designed goal. Occasionally, two neighbouring bunches were injected simultaneously, that may due to the unwanted micro bunches from the linac. This will be eliminated after the subharmonic bunching system is installed later. A wire scanner is being studied to get better match on the optics between linac and storage ring to increase the stability of the injection efficiency.

The two kickers are used for injection, thus the betatron phase advance between the two kickers is designed as 180 degree to form a local bump during injection. However, to reduce the residual orbit oscillation of the stored beam during injection, it's tricky to set the right timing and amplitude of the two kickers. This was done using the Libra BPM system [7]. The residual oscillations of the stored beam is measured and minimized while scanning the time delay and amplitude of each kicker in steps. Thanks to the sameness between the waveforms of the two kickers, after the time delay and amplitude of the two kickers was optimized for the injecting bunch, the residual orbit oscillation of all the other bunches during injection can be reduced to around 0.1mm, corresponding to about 0.1σ_x, as shown in Fig 2. This made it possible to inject beam during collision.

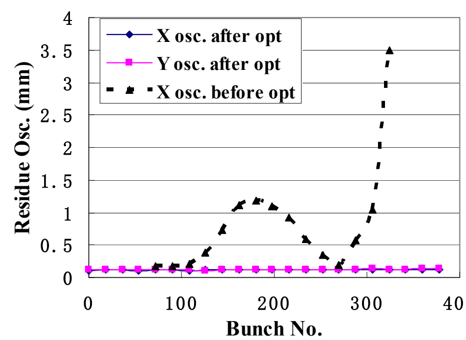

Figure 2: The residual oscillation of all bunches before (dashed line) and after (solid) the kickers optimized.

In most cases, one beam can be injected smoothly in collision with the other beam when the bunch current is below 7mA. But above 7mA/bunch, the injection of the second beam in collision becomes difficult with slow injection rate and beam loss monitors show significant dose. A horizontal separation at IP was helpful to get smooth injection. However, when the bunch current is high, say more than 7mA, it sometime leads to partial loss of one beam during the process to bring the two beams into collision. To investigate a better ways for smooth injection and stable collision with high bunch current is still under way.

Instabilities & feedback

The single bunch beam dynamics as well as collective effects is described in detail in ref. [8]. An analog bunch-by-bunch transverse feedback (TFB) system has been adopted to cure the instabilities [9].

In longitudinal, since SC cavity is adopted, the beam behaves fairly stable. However, synchrotron oscillation sideband was sometime observed along with beam current increase, but it seemed not caused by the beam instability, but by some noise in the LLRF loop. After the LLRF properly tuned, the beam is much stable in longitudinal direction up to 550mA with 99 bunches in both rings.

In transverse, coupled bunch instability was observed in both BER and BPR. In BER, vertical sidebands near the rf frequency was observed on the spectrum analyser. These may be due to resistive wall. In BPR, a broadband distribution of vertical sideband spectrum has been observed, which can be attribute to the electron cloud effect. With the TFB carefully tuned, the sidebands of couple bunch instabilities in both BER and BPR can be well suppressed, as shown in Fig. 3.

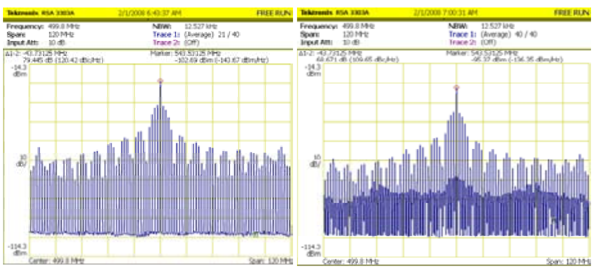

Figure 3: TFB turn on (left) and turn off (right)

Besides, streak camera was used to observe the vertical beam size blow up due to ECI, and there was not obvious grow up of the bunch size at the tail of the bunch train. As prevention to further ECI, solenoid has been winded on the vacuum chamber and can be put into use when needed.

Beam lifetime

The beam lifetime of single bunch is mainly limited by Touschek effect, and it behaves similarly versus bunch current in BER and BPR. The limitation of beam lifetime at high current operation seems dominant by the vacuum. Particularly, the vacuum pressure in BPR is about 70% higher than BER [10], this may lead to the shorter beam lifetime of BPR. Since there is slight blow up of beam size, the beam lifetime did not get worse during beam-beam collision.

However, the beam lifetime in both rings are shorter than expected from calculation, systematic studies are needed in the future.

LUMININOSITY TUNING

Single bunch collision

The two single bunches in each ring were brought to collision at the IP by Beam-Beam Scan (BBS). In phase one, beam-beam tune shift were measured and used to optimize the beam parameters for high luminosity. In phase two, a luminosity monitor (LUM) based on the detection of zero degree γ from radiative bhabha process was installed. It can distinguish the luminosity bunch by bunch and is fast enough to be used in the tuning procedures. Thus the beam parameters such as tune, coupling and local optics at IP were optimized to maximize the specific luminosity given by the LUM. The specific luminosity is defined as the luminosity divided by the number of bunches and also the product of bunch current of the two beams.

According to the beam-beam simulation the factional part of the transverse tunes were chosen near (6.54/5.59) for both rings. To get the best luminosity, tunes of each ring were scanned around the region. Then the tunes for BER and BPR were set near (6.54, 5.64) with two rings differed by about 0.005.

Optimization is also on the x-y coupling or beam size. This was done by adjusting the local vertical orbit in one sextupole in the arc. It's found that 1% coupling gives the best specific luminosity.

The vertical dispersion at IP was measured to be less than 10mm, and the contribution to the beam size at IP can be neglected. The local optical functions at the IP such as coupling and β_y^* waist were also adjusted to optimize the luminosity.

With the above beam parameters optimized, the maximum bunch current achieved in stable collision with high luminosity is 11mA by 11mA, which is higher than the design of 9.8mA.

Multi-bunch collision

For multi-bunch collision, it is important to have uniformly filled bunches. This has been configured in the injection control programme based on the event timing system. An algorithm has been developed to select the bucket with current below the limit set for each bunch according to the DCCT or Bunch Current Monitor (BCM), and then refill it with the rule of the smallest the first, thus, to get a uniform filling, as shown in Fig. 4.

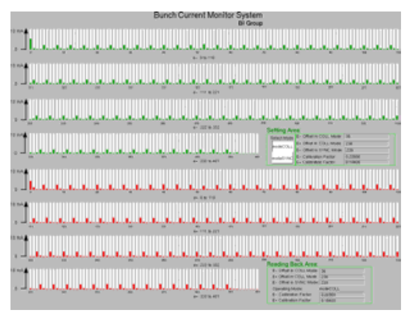

Figure 4: Display of uniform filling with BCM on 300mA×300mA multi-bunch collision.

Multi-bunch collision were practiced in two ways, one with relative high bunch current but small number of bunch, say above 7mA/bunch, the other is with moderate bunch current, but 93 bunches as designed. At same total beam current, the former case has the higher luminosity. But as mentioned before, the injection and collision process is not so stable. Thus, the best luminosity achieved was with 93 bunches at total beam current of 500mA, which is higher than $1\times10^{32}cm^{-2}s^{-1}$ with zero degree γ-detector, 10 times of BEPC.

The specific luminosity in multi-bunch case with high current seems lower than that with single bunch, shown in Fig. 5 [11]. One possible reason is the coupled bunch oscillation at high current. An indication is that when sometime the transverse feedback was better tuned, particularly at Y-direction, the luminosity could improve significantly.

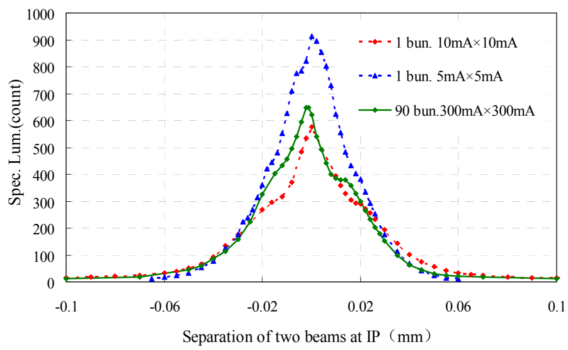

Figure 5: Spec. lum. of single(dashed) and multi-bunch (solid) vs. the vertical separation of two beams at IP.

Parasitic operation with wiggler

It is expected that SR user experiment can be carried out simultaneously during physics running. In the case with one wiggler 1W2 imposed, after the beam optics correction, the degradation of luminosity can be mitigated. Though the study is very preliminary, it proves in principle the feasibility of parasitic operation for SR use.

BACKGROUND

Experimental studies have been carried out to study the radiation dose around IP as well as the way to reduce the background. The main conclusion is that with the injection optimization the dose rate in the IR gets acceptable for the BESIII detector which is being pulled into the IR, and with collimators and masks, the background in the detector during its data acquiring could be well controlled. The details are introduced in ref. [12].

HIGH CURRENT ISSUES

Along with beam intensity growth, particularly when it is higher than 300mA, the heating effect due to SR and HOM may appear. Thus, more than 1000 thermal couplers were stick to the vacuum chamber, and the temperature at each location was displayed as bars in colour according to its dangerousness as green, yellow and red, respectively.

In most case, the temperature rise was due to the SR power increase. After the flux of cooling water adjusted, the heating was mitigated. However, some HOM heating appeared in the DCCT and the in-vacuum permanent wiggler 4W2, with the temperature rise shows the feature of sensitive to the bunch current.

For DCCT, though the RF shielding of copper layer to bridge the image current re-routing on the ceramic gap was adopted, its capacity seems not big enough for some low frequency part of the image current. Some capacitors will be connected to improve the RF shield.

For the 4W2, to prevent the magnet poles being over heated due to HOM, which may lead to demagnetization, a movable beam pipe designed to shield the HOM, was put into the right place. It functioned as expected and the temperature rise dropped to acceptable level even the beam current went up to more than 500mA, and no demagnetization observed.

Besides HOM heating, the orbit position measured by some BPM appeared sensitive to the beam current. This may attribute to the transverse wake field.

Nonlinear increase of vacuum pressure versus beam current was observed in BPR, as shown in Fig. 6. The threshold depends on the filling pattern. This may due to beam induced multipacting inside the beam pipe and can be one cause of the higher vacuum pressure in BPR. Solenoid winding may be helpful to ease the problem.

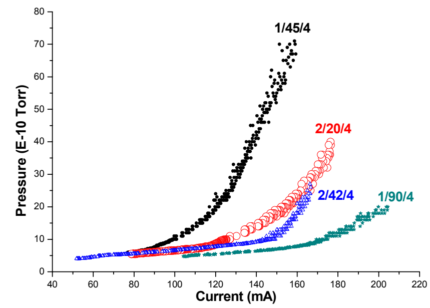

Figure 6: Nonlinear vacuum pressure versus beam current, with filling pattern marked on each curve.

SUMMARY

The optimization methods to achieve high current as well as high luminosity have been practice systematically. The beam current has reached more than 1/2 of design with no disastrous instabilities, and most devices performed stably as expected. However, there are still lot of issues for further studies such as to improve the specific luminosity at high beam current, to understand the beam loss mechanism, and so on.

The detector is being moved into the IR this spring, and the third phase commissioning is scheduled in early June. To improve the luminosity while control the background acceptable for data taking is still challenging.

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REFERENCES

[1] BEPCII Group, BEPCII Design Report, Aug. 2001.
[2] C. Zhang, these proceedings.
[3] C. Zhang et al, Proc. of APAC'07, India, Jan. 2007.
[4] J. Q. Wang et al, Proc. of PAC'07, U.S.A, July. 2007.
[5] J. Safranek et al, Proc. of EPAC'02, France, 2002.
[6] Y.Y. Wei et al, these proceedings.
[7] H.Z. Ma et al, internal report, Mar. 2008.
[8] Q. Qin et al, these proceedings.
[9] J.H. Yue et al, these proceedings.
[10] Q. Xiao et al, internal report, Mar. 2008.
[11] C.H. Yu et al, internal report, Mar. 2008.
[12] D.P. Jin et al, these proceedings.