THE BEPCII: STATUS AND EARLY COMMISSIONING

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Abstract

BEPCII is the upgrade project of Beijing Electron Positron Collider (BEPC). The installation of its storage ring components except the superconducting (SC) insertion magnets was completed in early November, 2006. While the improvement of the cryogenic system for SC magnets is in progress, the commissioning of the synchrotron radiation (SR) mode for the so called back-up scheme with conventional magnets adopted in the interaction region (IR), started on Nov. 13, 2006. The first electron beam was stored on Nov. 18 and later beam was provided to SR users for about 1 month starting from Dec. 25, 2006. The commissioning of the collision mode including the electron and positron rings started in Feb. 2007. The first beam collision was realized on Mar. 25. Then optimization of the beam parameters was done. On May 14, a 100mA to 100mA beam collision was achieved with 20 bunches for each beam. The luminosity estimated from the measured beam-beam parameters has reached that of BEPC. From May 25 the machine turns to the second run of the SR mode. This paper provides an overview of the construction and introduce the commissioning results of the backup scheme of BEPCII.

INTRODUCTION

The BEPCII is the upgrade project of BEPC, serving the purposes of both high energy physics experiments and synchrotron radiation applications[1]. The design goals of the BEPCII are shown in Table 1.

Table 1: The design goals of the BEPCII

Beam energy	1–2.1 GEV
Optimum energy	1.89 GEV
Luminosity	1×10^{33} $cm^{-2}s^{-1}$ @1.89 GeV
Linac Injector	Full energy inj.: 1.55–1.89GeV Positron inj. rate >50 mA/min
Dedicated SR	250 mA @ 2.5 GeV

It is a double ring e^+-e^- collider and a synchrotron radiation source with a bypass connecting its two outer half rings, or the SR ring (BSR). The layout and installed double-ring in the tunnel is shown as Fig. 1. For the collision mode, the electron ring (BER) and positron ring (BPR) cross each other in the northern and southern IP's. At the southern IP where the detector locates, a horizontal crossing angle of 11mrad×2 is designed to provide a quick separation of two beams but no significant degradation to the luminosity. While in the northern crossing region, the two beams cross horizontally and a vertical orbit bump is used to separate two beams, so that the optics of the two rings can be symmetric. For the dedicated synchrotron radiation mode, electron beam circulates in the ring made up of two outer half rings. In the southern interaction region, a special pair of superconducting magnet package (SCQ) 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. In the northern IP, a bypass is designed for the BSR.

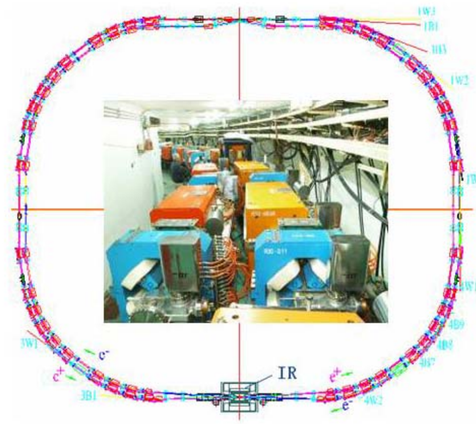

Figure 1: Layout and the installed two rings in tunnel.

The project started construction in the beginning of 2004. The upgrade of the injector linac was completed in late 2004. The BEPC ring was dismounted in July 2005. After 16 months' hard work, the storage ring installation was finished in early Nov. 2006, except for the cryogenics of the magnets, which needs some modification on the valve boxes and dewar. In order to provide beam to SR users as early as possible, meanwhile to accumulate experience on beam commissioning of double-ring collider, it was decided to install conventional magnets in the IR as the backup scheme, as shown in Fig. 2. The backup scheme has a similar lattice with the original design except that in collision mode the β_y at IP is 5cm instead of 1.5cm. In parallel with the commissioning of the backup scheme, the improvement of the cryogenic system and the measurement of the SC magnets are being carried out at the BESIII off-line position.

Figure 2: The IR with conventional magnets: the dipole in the middle is used in the BSR to connect outer half rings. Two quadrupoles on each side of the dipole are used in the collision mode for squeezing the beta function at IP.

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The commissioning of the beam started on Nov. 13, 2006 with BSR, as the first priority was to provide the beam to the SR users before the end of 2006. The first electron beam was stored on Nov. 18, 2006. The first run of SR operation was from Dec. 25, 2006 to Feb. 2, 2007, providing beam time of about 500 hrs. 11 beamlines and experimental stations were opened to the users with 92 experiments carried out. The commissioning procedure and the beam performance of BSR were reported on the APAC07 [2].

The following sections will mainly introduce the commissioning results of the collision mode of the storage ring. During the commissioning, the linac is also tuned to improve the injection rate, so a brief description on the performance of the linac is briefly reviewed first.

LINAC PERFORMANCE

The upgraded linac for e^- and e^+ beams was commissioned in 2005 and optimized in the first half year of 2006. Its main parameters have reached the designed value at least for short term, as shown in Table 2.

Table 2: The results of the linac commissioning

	Unit		Design	Measured
Energy	GeV		1.89	1.89
Beam current	mA	e^+	40	61
		e^-	>200	>500
Emittance	mm·mr	e^+	0.4	0.4
		e^-	0.09	0.1
Energy spread	%	e^+	0.5	0.50
		e^-	0.5	0.44
Repet. rate	Hz		50	50

The linac is well operated for both e^- and e^+ injection in the commissioning of collision mode either at 50Hz or 12.5Hz. A one-button operation has been developed to fast switch between the e^+ and e^- modes which improves the efficiency. However, the long term stability of orbit and energy, as well as the repeatability still needs improvement. A new subharmonic bunching system is being constructed to further enhance the e^+ injection rate roughly by a factor of 2.

BER AND BPR COMMISSIONING

Commissioning of BER and BPR started in February and March respectively. To make the injection relatively easier, a lattice with moderate β functions at the IP, i.e., β_x^*/β_y^*=2.5m/0.10m and the tunes of ν_x/ν_y=6.77/5.81 was chosen for both rings. 16 turn-by-turn Libera electronics, which can be switched to various BPMs in both rings, were used for first turn commissioning.

For the BER, the first beam was stored within 3 hours on Feb. 7, and later beam accumulation was realized on Feb. 9. For the BPR, taking the advantage that the BPR shares the same half ring as the BSR, the transport line of positron and the setting for injection kickers were tuned and optimized by injecting beam into the BSR first, then the positron beam was stored successfully on Mar. 4, just after about 24 hours from the beam injection to the BPR began.

The lattice modes for both BER and BPR were then changed to β_x^*/β_y^* = 2.0m/0.05m and working points near the half integers, i.e., ν_x/ν_y = 6.54/5.59 after the preliminary corrections on the lattice and orbit. No degradation on the injection rate and beam lifetime was observed. The growths of the beam current in the BER and BPR are shown in Fig. 3.

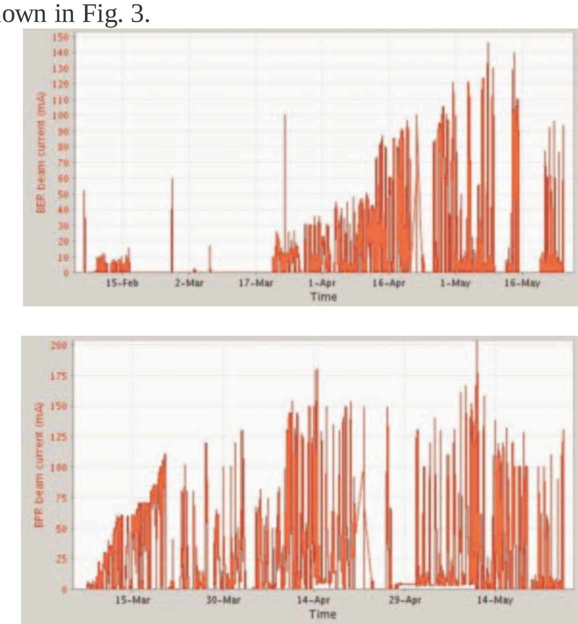


Figure 3: Current growth during the period of commissioning, BER (upper) and BPR (down)

For the first period of the BER commissioning, the beam current can not go up to 10 mA, as the SC cavity (SCC) tripped often due to the its vacuum pressure raised quickly and exceeded the threshold. The SCC was warmed up to 80K° during the spring festival shutdown in the end of January. After the commissioning of the BER resumed in the middle of March, the beam current could increase steadily, but was still limited by the vacuum of the SCC. The maximum beam current reached is about 145mA, which is near 1/6 of the full designed value.

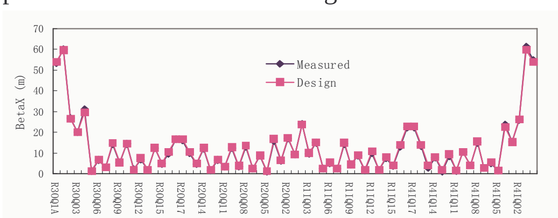
On contrast to the BER, the beam current of the BPR increases smoothly with a step of 10mA per day to reach more than 100mA in 2 weeks. The maximum beam current reached is about 180mA, which is near 1/5 of the full designed value. However, the maximum beam currents of both BPR and BER were restrained due to frequent RF trip in May.

BEAM PERFORMANCE

Optics and orbit

After beam storage and accumulation realized, all the BPM offsets were determined with beam-based alignment (BBA) and COD correction was done based on the measured response matrix between BPMs and correctors. After COD correction the average orbit deviation is about 0.2mm/0.08mm in horizontal and vertical planes, respectively, the rms orbit about 1.0mm/0.5mm. LOCO (Linear Optics from Closed Orbits) method [3] was applied to analyze and restore the optics functions of the BSR, BPR and BER.

Particularly, a fudge factor AF was used to describe the correction of each quadrupole strength to restore the optics, i.e., $k=k_0$*AF, where k is the quadrupole strength after correction and k_0 is the original one set for the theoretical lattice. When the fudge factors were applied to the storage rings, it led to good agreement between theoretical and measured beam optics functions with discrepancy within ±10% at most quadrupoles [4], as shown in Fig. 4. For the tunes, as an example, the design values of BER are 6.54/5.59, the measured values before correction are 6.57/5.61, and after correction are 6.5380/5.5903, which consists well with the design. The deviation of measured dispersion function from the design is also decreased.



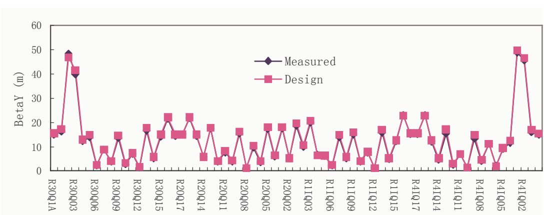


Figure 4: Measured and the designed β functions.

Table 2 summarizes the main parameters achieved for BER and BPR during this commissioning period.

Table 2: 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	145	180
Bunch curr. (mA)	9.8	>40	>40
Bunch number	93	93	93
RF voltage	1.5	1.6	1.6
Tunes (ν_x/ν_y)	6.54 /5.59	6.538 /5.590	6.539 /5.589
ξ_x/ξ_y	1.0/1.0	1.79 /0.95	1.35 /1.37
*ν_s @1.5MV	0.033	0.0308	0.0309
β_x^*/β_y^* (m)	2.0/0.05	1.19 /0.056	1.13 0.057
Inject. Rate (mA/min)	200 e^- 50 e^+	500	46
Energy spread(10^{-4})	5.26	5.12	5.21
$\lvert Z/n\rvert_0$ (Ω)	0.23	0.43	0.80

*ν_s is extrapolated from the measurement at RF voltage of 0.85 MV for BER and 1.25MV for BPR, respectively.

The fudge factors of quadrupole are mostly within 1.01~1.02, which means the real quadrupole strengths are lower than the design ones. One possible cause of this systemic component may come from the short distance between the quadrupole and its adjacent sextupole. However, this shall be verified by magnet bench measurement later. Other origin of these errors will be also pursued.

Instabilities

The single bunch current of both rings have reached 40mA with no disastrous instability. The bunch lengthening effect was measured with streak camera [5]. The bunch length is about 1.3cm at 0mA, and 1.5cm at 10mA, which is consistent with the design. The energy spread was measured from the quantum beam lifetime [6], and approached to the design as shown in Table 3. There is no significant energy spread increase when the bunch current is below 10mA.

The longitudinal broadband impedance was deduced from the tune shift with bunch current [5]. The result is shown in Table 3, there is difference between the BER and BPR, more study shall be done to confirm the result and check the cause. However, the measured impedance for both rings is less than 1Ω, which corresponds to the microwave instability threshold predicted in design [1]. This consists with the relatively weak bunch lengthening.

In the electron beam rings of both BSR and BER, sudden beam lifetime drop was observed and one possible explanation is dust trapping [7]. In the BPR, there is no evidence of Electron Cloud Instability (ECI) when the positron beam reaches 100mA, while in the BEPC ECI occurred at about 10mA in multibunch case. This indicates that the antechamber with TiN coating on the inner surface of beam pipe is effective to reduce the photo electron and SEY. Anyway, ECI in high beam current should be carefully monitored later.

Beam lifetime

The limitation of beam lifetime at high current operation seems dominant by the vacuum, for the integrate beam dose is still below 100 Ah. And in the BER and BPR, the beam lifetime of single bunch is of much concern, since the designed bunch current is about 10mA.

In some period, the beam lifetime in the BPR was less than that in the BER at the same bunch current. Then coupling was characterized to be responsible for the shorter beam lifetime of the BPR. When the couplings of the two rings are adjusted to about the same value, the beam lifetime is almost equal. But the beam lifetime at 9mA is about 2 hours, which is much less than that predicted by design as 7 hours. One possible cause may attribute to the bottleneck of the provisory beam duct in the back-up scheme. More studies are needed.

Injection

Efforts were mainly paid to improve the injection rate of positron beam. During the commissioning period, the linac was mostly operated at a repetition rate of 12.5Hz and the best injection rate realized is around 15-20 mA/min. When the repetition rate increased to 50Hz, after some primary tuning, the injection rate can be higher than 40mA/min. This gives confidence to reach the design value of 50mA/min. However, the injection rate was not so stable. This may be owing to the unstable performance of the linac and the lack of information on the parameters of the injecting beam which can be used for optics matching on injection.

For multi-bunch operation, it is important to have uniformly filled bunches. This has been configured in the injection control system using Bunch Current Monitor (BCM) system and the EVG/EVR timing system provides enough flexibility on the filling pattern. However, it seems not easy to get uniform bunches, for the injection efficiency is quite different from bucket to bucket. This may be due to some mismatch on the timing and amplitude of kicker or some beam instability caused by the injection oscillation. Optimizing the injection process and improving the injection efficiency are under way.

COLLISION TUNING

Beam-Beam Scan

The first Beam-Beam Scan (BBS) for collision at IP was done on Mar. 25. The BBS includes orbit scan in longitudinal, horizontal and vertical directions. In longitudinal direction, a BPM located on the common beam pipe of two rings near IP was used to measure the difference on the arrival time of two beams to IP. By properly adjusting the RF phase in either ring, the two beams can be brought to the nominal IP at the same time. Then BBS was done in horizontal and vertical planes. For this purpose, an orbit bump around the IP in one ring is used to scan the beam position at the IP, while observing the beam orbit variation in the other ring due to the beam-beam deflection. The first BBS was tried with a single bunch in each beam. Fig. 5 is one typical BBS result.

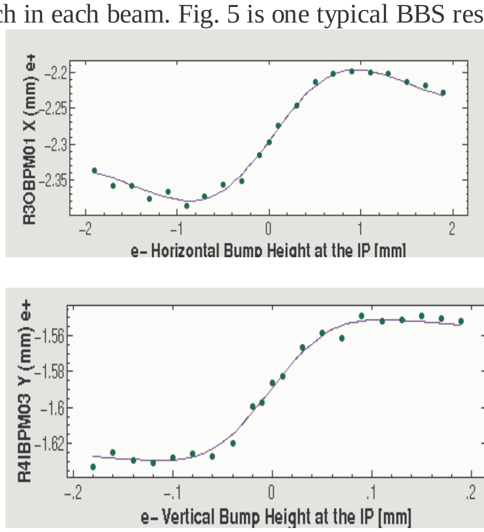


Figure 5: Positron beam orbit variation due to beam-beam deflection scanned with local orbit bump of electron beam at IP (a) in horizontal plane, (b) in vertical plane. The lines are the fitted curves for Gaussian bunches.

The beam size and IP position can be obtained by fitting the BBS data. For one scan, the beam size is σ_x^*/σ_y^*=0.5mm/0.016mm [8], which is comparable to the design value of σ_x^*/σ_y^*=0.5mm/0.012mm. However, the vertical beam size is larger than the design one, this may be due to the beam-beam blow up. From the beam size, the luminosity can be estimated as 7.8×10^{29}cm^{-2}s^{-1} of 5mA×5mA collision.

Besides the orbit scan, the coupling at the IP can be adjusted by tuning the 4 skew quadrupoles in each ring. β_y^* waist scan was tried by fitting the strengths of a set of quadrupoles located on the two sides of the IP. The above adjustment was done referring to the count rate from the zero degree luminosity detector. But since the beam duct in the IR are only for temporary use in the backup scheme which did not optimized for background consideration. The S/N ratio is rather poor and the count rate can only serve as a rough relative reference when tuning the beam-beam collision with the above methods.

The fine tuning of the collision conditions such as tunes, orbit, bunch sizes, etc., needs more work and can only be done with a reliable luminosity detector. BBS is reproductive in successive several shifts. But sometimes, the conditions drifted. The reason needs to be investigated.

Beam-beam Tune Shift

The performance of beam collision can be evaluated by the beam-beam tune shift. The sweep frequency method was used for the tune measurement while the transverse feedback kicker serving as the shaker to excite the beam oscillation. The perturbed tunes of each ring corresponding to the so called high tune (H) and low tune (L) modes have been observed with spectrum analyzer [9][10]. Figure 6 is the typical tune spectrum observed during two single bunches collision.

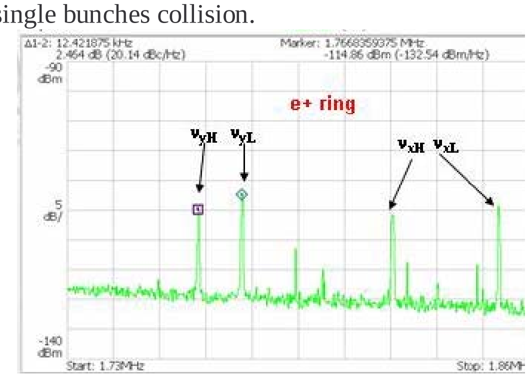


Figure 6: Measured tunes due to beam-beam effect.

Since BER and BPR have symmetric lattices, they have almost the same tune. Thus the horizontal and vertical tune beam-beam shifts can be simplified as $\Delta\nu_x=\nu_{xH}-\nu_{xL}$ and $\Delta\nu_y=\nu_{yH}-\nu_{yL}$, respectively. However, the measured tune shift strongly depends on the strength of the shaker. For one collision, the weaker the shaker, the larger tune shift can be measured, particularly in the vertical direction. This can be understood as the shaker can cause the increment of vertical beam size. In most cases, the tune shift signal is relative clear below 3mA per beam. With BBS to set the collision orbit, we optimize the coupling to maximize the tune shift. One typical data is $\Delta\nu_y$ =0.02 at a collision of 3mA×3mA. The highest single bunch current for stable collision achieved is about 7mA. From the tune shift, the luminosity can be estimated as 0.5~1.0×10^{30} $cm^{-2}s^{-1}$ at 5mA×5mA, which is in consistent with that calculated from the beam size.

Multi-bunch collision

Multi-bunch collision was tested several times. On the histogram of luminosity count rate, a same number of peaks in equal amplitude were observed corresponding to that of bunches. This indicates that the luminosity scales linearly with the bunch number. On May 14, a 100mA to 100mA beam collision was achieved with 20 bunches for each beam. The luminosity estimated is higher than 1×$10^{31}$$cm^{-2}s^{-1}$ which is the record of BEPC.

Background

Detectors with PIN diodes and RadFETs are used to assess the radiation dose rate around IP. It was found that the dose rates during injections are much higher than the steady runs with stored beam. One possible cause is the present provisory IR beam pipe constitutes a bottleneck for the injected beam. However, this pushes us to improve the injection efficiency in future commissioning and speed up the manufacture of the masks for background.

EQUIPMENT PERFORMANCE

For the 6-month commissioning and operation, almost all the accelerator components have been examined and most of them function well. The control system and beam diagnostic instrumentation improved day by day. During the first turn beam commissioning of each ring, only few hardware problems such as misconnection of power supply and wrong polarity of magnet were encountered but soon fixed. This led to the rapid storage of beams.

Equipment problems contributing to the relatively long time missing of beam (10s hrs to several days), which can be seen on Fig. 3 as some blank, include: 1) 4 times breakdown of rectifier transformer of main dipole power supplies in the rings, which is pure quality problem. 2) the failure of compressor of cryogenic system or the quench of RF cavity, etc., which is due to the malfunction or lack of experience.

In early stage of commissioning, RF trip frequently occurred due to vacuum, arc, quench, klystron pump PS, and sometimes noise, 2-3 times per day on average. This was improved later.

PROGRESS OF SCQ

In parallel with the beam commissioning, the improvement of the cryogenic system and test of superconducting IR magnets (SCQ's) were pushed on. An insulation vacuum section was added to the neck of 1000L Dewar to reduce the heat loss and the valve boxes were rebuilt with new power leads, helium route and improved structure. After these modifications, the two SCQs and the superconducting solenoid magnet (SSM) for detector were cooled down together in May. Then the power supplies and quench protection systems of SCQs were tested. On June 11, the two SCQs and the SSM were successfully excited to their full design currents at the same time. This condition was kept for more than 10 hours and the whole system worked stably. The combined magnetic field measurement of SCQ's and SSM is being carried out. Fig.7 pictures an SCQ with the BESIII detector at the off-line position.

Figure 7: SCQ with detector.

PLAN AND SCHEDULE

The SCQ's are scheduled to move into the IR after the combined field measurement is accomplished in this August. Beam commissioning with SCQ's is planned in early October. It is expected that the BESIII detector can be moved into IR in the spring 2008 when a sufficient high luminosity with low background is hoped to be achieved.

ACKNOWLEDGEMENT

For the construction of SCQ and cryogenic system, we appreciate the many help from BNL, DESY and KEK. For SCRF operation, Drs. Furuya, Mitsunobu and Akai from KEK help a lot. For beam commissioning and lattice analysis, SAD was transplanted from KEK and LOCO from SLAC is used. Dr. Fisher from SLAC joined the first days of BSR commissioning, giving helpful advices. Thanks also go to the BEPCII IMAC members.

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