LATTICE DESIGN FOR THE BEPCII STORAGE RING

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Abstract

BEPCII, the upgrading project of the BEPC, has been being designed with a luminosity of 10^{33} $cm^{-2}s^{-1}$ at the J/ψ energy. It still keeps the potential to provide beams as a synchrotron radiation (SR) facility. The storage rings for collision contain a positron and an electron ring and the ring for dedicated SR uses the outer parts of the two rings. To fit all the conditions either on beam or on space limit, lattices are carefully designed for both high energy physics and SR experiments with sufficient dynamic apertures and high efficiencies for injection. The features of the lattices are also discussed in the paper.

1 DESIGN REQUIREMENTS

BEPCII is an upgrade project of the Beijing Electron-Positron Collider (BEPC), in which a new inner ring will be installed inside the old one. It will provide colliding beams with the center-of-mass energy from 1.0GeV×2 to 2.0GeV×2 and also the dedicated synchrotron radiation beam with 2.5 GeV. For the colliding beams the luminosity is optimized at 1.89 GeV with 1×10^{33} $cm^{-2}s^{-1}$. For the dedicated synchrotron radiation beam, the current is 250 mA with an emittance as low as possible.

There have been several beam-lines in the BEPC for the synchrotron radiation experiments, so the current bending magnets and insertion devices in the southern region have to be fixed at their present positions.

In order to increase the average luminosity, the “topoff” injection scheme up to 1.89 GeV is adopted. This requires that the injection and collision optics must be the same.

The main parameters are shown in Tables 1 and 2.

Table 1: Main Parameters of BEPCII Colliding Mode

Energy E	GeV	1.89
Circumference C	m	237.53
RF frequency f_{rf}	MHz	499.8
RF voltage V_{rf}	MV	1.5
Damping time $\tau_x/\tau_y/\tau_E$	ms	25/25/12.5
Beam current I	A	0.91
Bunch number n_B		93
SR power P	kW	110
Energy spread σ_ε		5.16×10^{-4}
Momentum compact α_p		0.0235
Bunch length σ_z	cm	1.5
Emittance $\varepsilon_x/\varepsilon_y$	nm·rad	144/2.2
β-function β_x^* / β_y^*	m	1/0.015
Crossing angle at IP ϕ_c	mrad	11× 2
Bunch spacing s_b	m	2.4
Beam-beam ξ_x/ξ_y		0.04/0.04
Luminosity $\mathcal{L}$	$cm^{-2}s^{-1}$	1.0×10^{33}

Table 2: Main Parameters of BEPCII SR Mode

Beam energy E	GeV	2.5
Circumference C	m	241.13
RF voltage V_{rf}	MV	1.5~3.0
SR loss/turn U_0	keV	336
Beam current I	A	0.25
SR power P	kW	84

2 GEOMETRIC DESIGN

Being upgraded from BEPC, BEPCII will use the old tunnel and keep the present beam-lines, so that the circumferences of “three rings” (two colliding rings and the synchrotron radiation ring) and the distance between the outer and inner rings is only adjustable in a few tens of centimeters. In the meantime, in order to increase the injection rate, especially the positron case, the two-bunch injection from linac is helpful. The RF frequency of the colliding rings is also constrained by the linac frequency. On the other hand, in selecting the RF frequency, considerations must be given to the demands of the harmonic number from the DAQ (data acquisition) system of the BESIII detector. The final choice of the RF frequency is 499.8MHz, which is 7/40 of the linac frequency 2856MHz. Corresponding to this frequency, the harmonic numbers for the colliding and synchrotron radiation rings are 396 and 402, respectively. The distance between the outer and inner rings is 1.18 m. The north half ring of BEPC must shift 0.36 m northward. The two-bunch injection scheme is to inject the No. 1 and 29 RF buckets of the ring, corresponding to No. 1, 2, 3 and No. 161, 162, 163 buckets of the linac.

BEPCII consists of two horizontally separated rings. Due to the very tight space, the only way to separate the two beams is to use the crossing angle at the IP. The crossing angle of BEPCII is chosen as 11mrad × 2. But the crossing angle cannot give a sufficient separation, the first pair of defocusing quadrupoles of the IR will deflect the beams further to 27 mrad × 2 and then a pair of septum magnets deflect the beam in the inner rings to 64.4 mrad. The reason that the septum magnets only deflect the beams in the inner rings is to avoid the synchrotron radiation background in the IR. The synchrotron radiation mode needs a bridge to connect the two half outer rings. There are two superconducting dipole coils on both sides of the IP to accomplish this function. The beam will have 4.5 mm horizontal offset at the bending coils for the synchrotron radiation mode. In the RF region, the crossing angle of the trajectories of the electron and positron beam is 154.7 mrad × 2. Since the crossing point has a 0.15 m offset to the symmetric axis, the effects on the parasitic beam-beam interaction can be omitted totally. During the synchrotron radiation mode operation, the bridges, which connect the inner and outer rings, will be powered off. Thus, the electron beam will go straight through the bending magnets. In this case, both of the RF cavities can provide the power to the electron beam. Fig. 1 shows the BEPCII complexity.

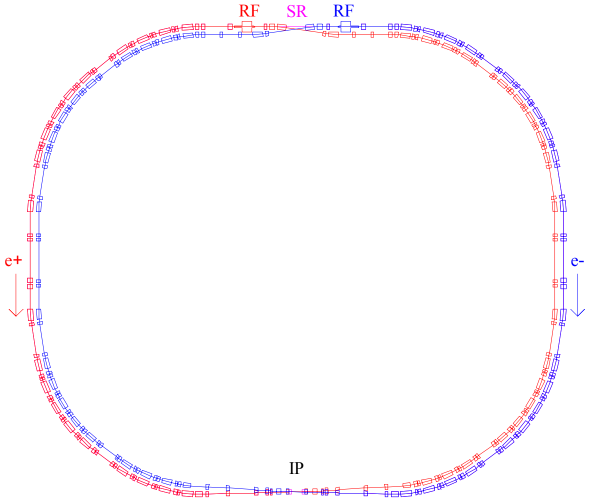

Figure 1: The BEPCII Complexity

3 OPTICS DESIGN OF BEPCII

3.1 Lattice Design of the BEPC

The BEPC [1], which has a 4-fold symmetric structure, consists of the IR/RF, the arc and the injection regions. In the IR/RF region the dispersion is free, so 4 quadrupoles (Q1, Q2, Q3 and Q4) can connect the beta function between the IP and the arc. In the injection region the dispersion is also free. In this region there are two quadrupoles (Q16, and Q17) to match α_x and α_y at the symmetric point to 0, and a Lambertson septum for each beam is used to transfer the injecting beam from the transport line into the ring. Actually, the injection region can be extended to the two kickers, which locate just before Q15. In order to decrease the equivalent thickness of the septum the beta function at the septum is optimized as large as possible, so Q17 is chosen as focusing. The horizontal phase advance between the two kickers is designed nearly 180°. The arc region consists of 6 quasi-FODO cells except missing the fifth and eleventh bending magnets. By abstracting the fifth and eleventh bending magnets, the emittance of the lattice can reach a large value easily. For saving the longitudinal space there is no special region for dispersion suppressing. Actually each region is not independent of the other, any change about the optics has to change all quadrupoles in a quarter.

3.2 Lattice Design of BEPCII

The double-ring geometric structure of BEPCII makes each ring of BEPCII not to be a 4-fold symmetric structure, and no symmetry exists between the electron and positron rings. There are two reasons: one is that the crossing point in the north is not at the symmetric point for avoiding the beam-beam interaction, the other one is that the very tight longitudinal space and the different vacuum chamber types (ante-chamber for the positron ring and racetrack chamber for the electron ring) lead to the different mechanical arrangements in the arc regions. Each ring of BEPCII can be divided into four regions: the IR, the arc, the injection, and the RF regions.

In the IR region the superconducting quadrupole SCQ is a defocusing quadrupole to squeeze the vertical beta function at the IP. It also bends the beams further from 11 mrad to 27 mrad. The warm bore quadrupoles Q1, Q2, Q3, and Q4 are used for connecting the arc and IP. In order to reduce the fabrication difficulty of Q1, the focusing quadrupole Q1 is divided into two pieces, Q1a and Q1b. R3OBL1 and R4OBL1 are low field bending magnets to decrease the synchrotron radiation at the IP. Q1a and Q1b are special dual aperture quadrupoles. For Q1a and Q1b, the gradients in the inner and outer rings are equal. Q2 is also a special quadrupole but the gradients in the inner and outer rings can be changed independently in the inner and outer rings. Q3 and Q4 are regular quadrupoles as that in the arc region. In the design, the beta functions at the IP are 1.5 cm in the vertical plane and 1 m in the horizontal plane. The optics in the IR regions is shown in Fig. 2.

According to the requirement of the detector physics, the strength and length of the detector solenoid are 1.0 Tesla and 1.8 × 2 meter, respectively. It is very high compared with the 0.4 Tesla solenoid of the BEPC. Since the longitudinal space in the IR is very tight, it is difficult to find a compensation scheme using the skew quadrupoles' system. The best way is to compensate the coupling locally inside the detector with using anti-solenoids and skew quadrupoles.

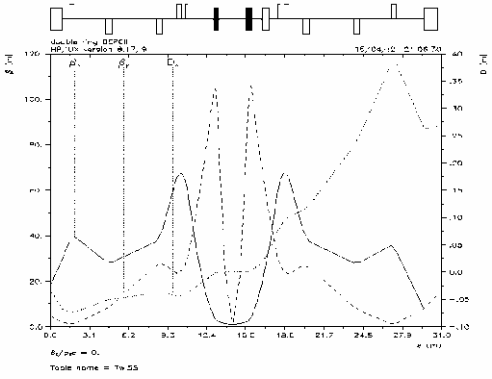

Figure 2: Optics in the IR Region for the Positron Ring

In the RF region, there are seven quadrupoles to connect the arc regions of the inner and outer rings. Due to the limited space in both transverse and longitudinal planes, it is not possible to arrange the magnets symmetrically in the inner and outer rings. But basically the arrangement is symmetric between the electron and positron rings except for the crossing point located 0.15m away from the symmetric point. The dispersion in the parts of outer rings is free, and the beta functions at the

RF cavities in both vertical and horizontal planes are less than 15 m.

At the injection point, the dispersion is free as well as the same location in the inner rings. The beta function is larger than 20 m to reduce the sigma amplitude of the remnant oscillation of the injected beam. The phase advance between two kickers is exactly 180°.

The main consideration of the optics in the arc region is to meet the designed emittance and the sufficient dynamic aperture. The general rules in the arc regions are: the beta functions in both vertical and horizontal planes less than 25m, dispersion in horizontal plane less than 2.5m, the horizontal beta function at focusing sextupoles and the vertical beta function at defocusing sextupoles as large as possible. Moreover, the limited vertical aperture at the insertion devices will lead to the constraint of the vertical beta function.

Similar to the BEPC, the different regions are not independent from others. This means if a certain parameter needs to be changed, the twiss functions have to be changed in the whole ring. The difficulties in the operation can be expected.

4 CHROMATICITY CORRECTION AND DYNAMIC APERTURE

A sufficient dynamic aperture is necessary, either for efficient beam injection or long beam lifetime under colliding in BEPCII. Though the requirements for the injection and the colliding beams are slightly different, we use the condition of the injection beam for both cases, which means a larger momentum acceptance $(\sim 12\sigma_\varepsilon)$ and larger transverse apertures. For the tracking results evaluated here, the horizontal RMS beam size is taken from the natural horizontal emittance of the ring, and the vertical beam size σ_y from the fully-coupled emittance, i.e., half of the uncoupled horizontal emittance.

The linear lattices are designed using the MAD [2] program. Errors including misalignments and magnetic multipoles are assigned to the thin lens multipoles attached on the main magnets using the MAD program too. Particles are launched at the IP with 2048 turns for the dynamic aperture tracking.

Here, we focus on the tracking studies for the positron ring, since the electron ring has the similar structure.

The sextupoles are used to correct the chromaticity (ξ_x = -11.9 and ξ_y = -25.4) in the BEPCII storage ring. Each arc has 9 sextupoles, which are divided into 3 families of defocusing sextupoles (SD) and 2 families of focusing sextupoles (SF). The families of sextupoles are set as SD1, SF1, SD1, SF1, SD2, SF2, SD2, SF2, SD3, from the IP to the injection region in the southern half of BEPCII, and the same sequence of sextupoles from the injection region to the RF region in the northern half. So, 2-folder symmetry exists in the sextupole arrangement.

With these sextupoles, chromaticities of the BEPCII storage ring are corrected to 1.0 in transverse. The second and third order chromaticities can be corrected to the orders of 10 and 10^3, respectively. Without the limit of longitudinal momentum acceptance due to the RF cavity, particles are still stable between $\Delta p/p$ = –2.2%~1.8%. Within the momentum deviation range of ±0.6%, the beta functions change by less than 20% and tunes 0.2%.

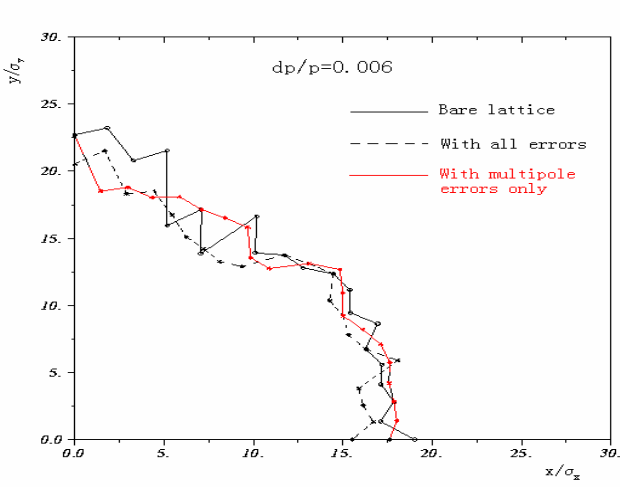

Figure 3: Dynamic aperture for off-momentum

5 OPTICS DESIGN OF SR MODE

The BEPCII is a double ring electron-positron collider. However, in the BEPCII complex there is another electron ring that is called SR ring and can be used as a light source. The ring is formed by connecting two outer half-rings of the electron and positron rings. The design goal of the SR mode is: electron energy is 2.5 GeV and the maximum beam current is 250 mA. We chose the betatron tunes as ν_x=8.18 and ν_y=5.28. The emittance is 138 nm·rad at 2.5 GeV. The emittance of the BEPCII SR mode is larger than that of the BEPC, which is about 103 nm·rad at 2.5 GeV. The maximum beta functions β_x and β_y are smaller than 23 m in both the horizontal and vertical planes. The maximum horizontal dispersion function D_x is about 1.65 m. The natural chromaticities are ξ_x = -10.9 and ξ_y = -8.6 for the horizontal and vertical planes respectively. The dynamic aperture is larger than 25σ even with 1% energy spread.

6 SUMMARY

A detailed lattice design has been performed. The geometric design satisfies both colliding mode and synchrotron radiation mode requirements. The emittance and tunes for the colliding mode are very flexible. The lattice offers a good dynamic aperture even with 0.6% energy spread, multipoles' error and the misaliagnment effects. For the synchrotron radiation mode, we also have got a preliminary optics design.

7 REFERENCES

[1] S. Fang, et al., Improvements to the BEPC Storage Ring Lattice. High Ener. & Nucl. Phys. 10, 1986

[2] H. Grote and C. Iselin, The MAD Program, CERN/SL/90-13(AP)