STUDY ON THE BEPCII LATTICE*

Y. P. Sun#, Key Laboratory of Heavy Ion Physics, Peking University& IHEP, Beijing
J. Gao, IHEP, Beijing; Z. Y. Guo, Key Laboratory of Heavy Ion Physics, Peking University, Beijing

Abstract

BEPCII, the upgrading project of the Beijing Electron-Positron Collider (BEPC), has been designed with a luminosity of 10^{33} cm^{-2}s^{-1} at the τ-charm energy region. According to the beam-beam simulation results, the luminosity of BEPCII with a crossing collision angle of 11 mrad is about 0.50×10^{33} cm^{-2}s^{-1} with the original operation mode at the working point of 6.53/5.58. To increase the operating luminosity of the BEPCII, a low momentum compaction factor (α_P) collision mode has been studied which can increase the luminosity to 0.54×10^{33} cm^{-2}s^{-1}. If the bunch length of the low α_P mode is reduced from 1.5 cm to 1.2 cm, a mode with vertical beta function at IP equal to 1.2 cm could push the luminosity to 0.828×10^{33} cm^{-2}s^{-1} at the working points 6.53/5.56. Also, the BEPCII synchrotron radiation mode is optimized to get a larger dynamic aperture and much more stable tunes.

ON COLLISION LATTICE

BEPCII is an upgrading project of the Beijing Electron-Positron Collider (BEPC), where a new inner ring will be installed inside the old one. The double-ring geometric structure of the BEPCII makes each ring not to be a 4-fold symmetrical structure, though symmetry still exists between the electron and positron rings. Based on several design criteria, a geometric design which satisfies both collision and synchrotron radiation modes requirements is done [1].

From Eq. 1, one can calculate the head-on collison luminosity

$$L(\mathrm{cm^{-2}s^{-1}}) = 2.17\times10^{34}(1+R)\xi_y \frac{E(GeV)k_b I_b(\mathrm{A})}{\beta_y^*(\mathrm{cm})} \quad (1)$$

where $R = \sigma_y^*/\sigma_x^*$ is the beam aspect ratio at the interaction point (IP), ξ_y the vertical beam-beam parameter, E the beam energy, β_y^* the vertical envelope function at IP, k_b the bunch number in each beam and I_b the bunch current.

The beam-beam interaction simulation was carried out with several computer codes, which shows a luminosity reduction in different degrees compared with the designed luminosity. The results from one of the codes show that the luminosity of BEPCII with a crossing collision angle of 11 mrad is about 0.50×10^{33} cm^{-2}s^{-1} with the original operation mode at the working point of 6.53/5.58 [2]. To increase the luminosity of BEPCII, in this paper we will discuss how to adjust the lattice to reach high luminosity. First, the BEPCII lattice is adjusted to reduce the momentum compaction factor α_P while keeping the vertical beta function at 1.5 cm [3]. The corresponding luminosity can be increased to 0.54×10^{33} cm^{-2}s^{-1}. The threshold of microwave instability can be estimated according to the Boussard or the Keil-schnell criteria [4]:

$$I_{th} = \frac{\sqrt{2\pi}\alpha_p \frac{E}{e}\sigma_{e0}{}^2\sigma_{l0}}{R\left|\frac{Z}{n}\right|_{eff}} \quad (2)$$

For low alpha mode, α_P=0.0188, σ_{l0}=1.08 cm, other parameters are the same as in the original mode [1], it can be calculated from Eq. 2 that the threshold of microwave instability will be 34 mA which is much larger than the BEPCII designed single bunch current 9.8 mA.

Secondly, the quadrupoles in the ring are adjusted to give the vertical beta function equaling to 1.2 cm at IP, with the working point kept at 6.53/5.58 [5]. Finally, with the vertical beta function being 1.2 cm at IP, the working point is moved to 6.53/5.56. At the same time, maintaining a low horizontal emittance is very important for gaining a high luminosity.

In the following sections, the matching procedure for the lattice with α_P=0.0188 and β_y^*=1.2cm, the chromaticity correction, and the dynamic aperture tracking results are presented.

As the vertical beta function at IP should be decreased to 1.2 cm, the strength of the quadrupole in the mini-beta insertion should be increased. Here the K1 value of R3OQ1A is kept the same as the original value 1 and the K1 value of R3OQ1B is adjusted from 0.7232 to 0.73. The quadrupoles in region 3 and 4 are adjusted to satisfy other criteria. The quadrupoles in Region 1 and 2 is not changed. In that way the phase advance between kickers and the beta function at the RF cavity are not changed.

The TWISS parameters of the ring are shown in Figure. 1.

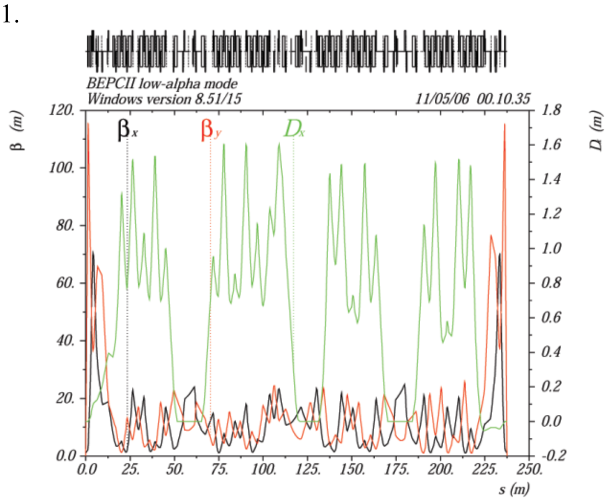

Figure 1: TWISS parameters of the BEPCII high luminosity collision mode

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# ypsun@ihep.ac.cn

Nine sextupoles in each arc region are used to correct the first order chromaticity from negative values to 1 and the second order chromaticity bigger than 15. The third order chromaticity is also controlled. They are divided into 5 families of defocusing sextupoles (SD) and 4 families of focusing sextupoles (SF). The families of sextuples are set as SD1, SF1, SD2, SF2, SD3, SF3, SD4, SF4, and SD5 from the IP to the injection region in the southern half ring and from the injection region to the RF region in the northern half ring.

The tune variation and beta function variation at IP versus momentum deviation up to ±0.6% are shown in Figure. 2. Tracking for 1024 turns with 10 seeds using SAD [6], the dynamic aperture with all magnets errors is shown in Figure. 3.

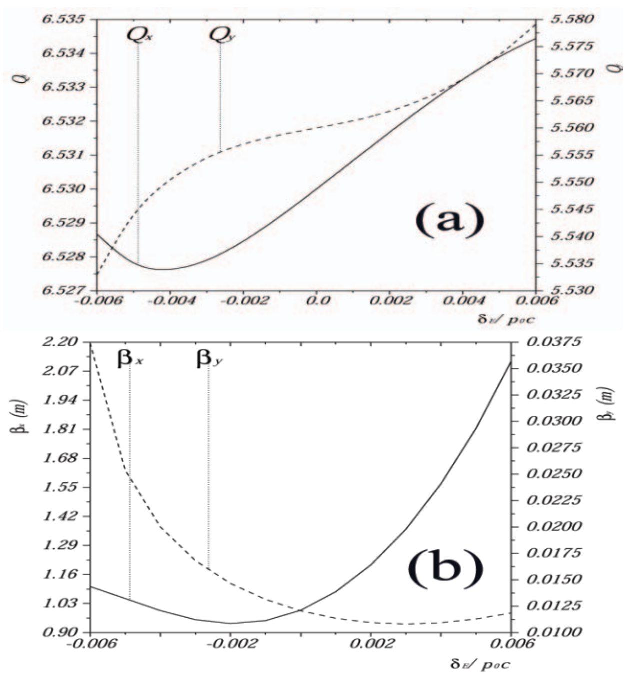

Figure 2: (a) Tunes of the ring vs $\delta p/p$ up to 0.6%; (b) Beta functions at IP vs $\delta p/p$ up to 0.6%.

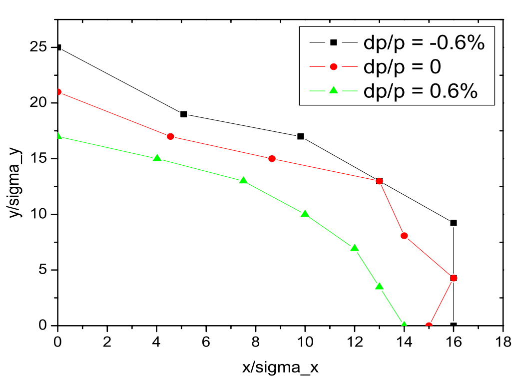

Figure 3: Dynamic aperture calculated using SAD.

ON SYNCHROTRON RADIATION LATTICE

The synchrotron radiation ring is consisted of the two half outer rings of BEPCII. The main parameters of the synchrotron radiation ring are listed as follows: energy 2.5 GeV, circumference 241.13 m, natural chromaticity -8.9/-8.1, tunes 7.28/5.12, horizontal emittance 138 nm.rad, momentum compaction factor 0.015, natural bunch length 0.0117 m, natural energy spread 6.5×10^{-4} [7].

Tracking for 1024 turns using AT (Accelerator Toolbox) [8], the dynamic aperture of BEPCII SR ring is obtained. The results show that the dynamic apertures of off-momentum particles are not good.

Frequency map analysis (FMA) is introduced for the demonstration and understanding of the chaotic behavior of a dynamical system. The application to particle accelerator dynamics is done in the case that the motion of a single particle in a storage ring is described in a surface of section of the beam by a symplectic map of dimension 4 or 6 [9].

Here FMA is performed on the original BEPCII SR lattice, and the results show that the resonance is very severe and the transverse motion is unstable.

Set the horizontal working point in the region (7.2, 7.4) and the vertical working point in the region (5.0, 5.2), the resonance lines up to 6-order are drawn out. From this analysis it can be seen that the working point 7.28/5.12 is on one 5-order resonance line exactly and there are many dangerous sum-resonance lines around this working point. That may be the main reason why the dynamic aperture is not good in this lattice.

For synchrotron radiation use, it is very important to achieve a large dynamic aperture and a stable transverse tune. So the BEPCII SR lattice needs to be optimized to achieve these goals. As the BEPCII SR lattice consists of the two outer half rings of BEPCII lattice and two-fold symmetry exists in the SR lattice, the super periodic structure resonance will be all the integers. So the working point should not be too close to the integer. At the same time the working point should be chosen to be far away from the dangerous resonance lines. Based on these requirements the working point is chosen to be around 7.12/6.3.

In the following sections, we will present the matching procedure for the new lattice, the chromaticity correction, the dynamic aperture tracking results, and the FMA analysis results.

The matching criteria is as follows: (1) The beta functions are less than 30 m and greater than 1 m in the whole ring; (2) The horizontal beta function is greater than 8 m at the position of the injection kickers; (3) The horizontal phase advance is π exactly between the two injection kickers; (4) The vertical beta function in the injection point is greater than 6 m; (5) The beta functions at the RF cavity are less than 15 m; (6) The natural chromaticity should be as small as possible; (7) The emittance should be as small as possible; (8) Use distributed-dispersion to decrease the emittance.

Following these matching criteria and the requirements for selecting a proper working point, the linear lattice matching [5], chromaticity correction and FMA tracking process are repeated. After optimization the linear lattice is gotten and shown in Figure. 4, where the solid line is the horizontal beta function, the dashed line is the vertical beta function, and the dotted line is the horizontal dispersion function. The main parameters of the new lattice are listed as follows: energy 2.5 GeV, circumference 241.13 m, natural chromaticity -9.0/-8.2, tunes 7.12/6.3, horizontal emittance 145 nm.rad, momentum compaction factor 0.015, natural bunch length 0.0119 m, natural energy spread 6.4×10^{-4}.

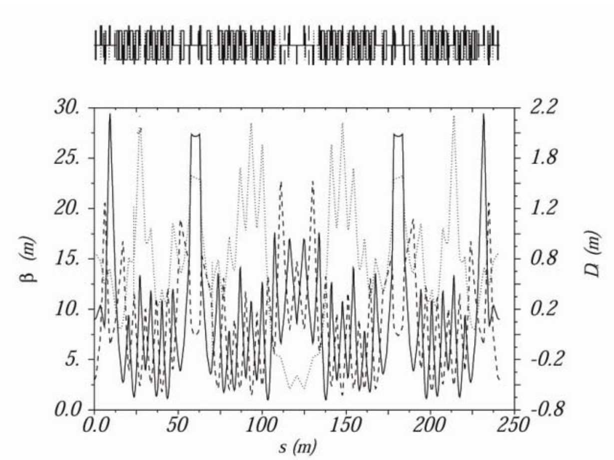

Figure 4: TWISS parameters of the BEPCII synchrotron radiation mode after optimization.

Nine sextupoles in each arc region are used to correct the first order chromaticity from negative values to 1. The second and third order chromaticity is also controlled. These sextupoles are divided into 3 families of defocusing sextupoles (SD) and 2 families of focusing sextupoles (SF). The families of sextuples are set as SD1, SF1, SD2, SF2, SD3, SF2, SD2, SF1, and SD1 from the IP (Interaction Point) to the injection region in the southern half ring and from the injection region to the RF (Radio Frequency) region in the northern half ring.

The tune variation and the beta function variation at IP versus momentum deviation up to 1% are less than 20%. Tracking for 1024 turns using AT [8], the dynamic aperture of the optimized BEPCII SR lattice is obtained. The optimized dynamic apertures of both on-momentum and off-momentum particles are good and they are about 15% to 20% larger in comparison with the original values.

As the nonlinear wiggler effect is not included in the tracking process, we use analytical method to calculate the dynamic aperture of the SR lattice with ideal nonlinear wigglers [10]. The results show that for both on-momentum and off-momentum particles, the dynamic apertures only decrease less than 20% after nonlinear wiggler effect is added in.

Here FMA is performed on this lattice where 2500 on-momentum particles are tracked for 2000 turns, and the result is shown in Figure 5. In this optimized lattice the resonance is not so severe and the transverse tunes are much more stable.

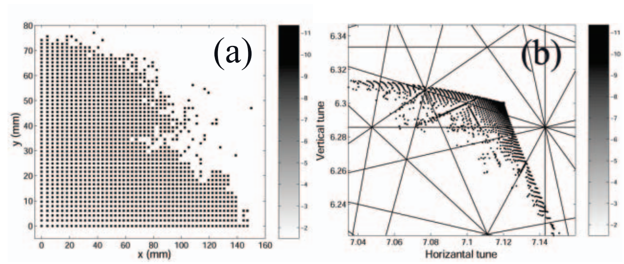

Figure 5: (a): DA with FMA; (b): Footprint on tune space

CONCLUSIONS

A low α_P low β_y^* collision mode for BEPCII has been developed. The aim is to increase the luminosity by reducing the vertical beta function at IP from 1.5 cm to 1.2 cm and to move the working point to high luminosity region. The dynamic aperture is acceptable for collision but still a little small for injection. So the BEPCII ring can be tuned to these modes after the beam has been injected into the ring. For the natural bunch length of 1.08 cm and the vertical beta function of 1.2 cm, the highest luminosity reached is 0.828×10^{33}cm^{-2}s^{-1} at the working point 6.53/5.56 with the assumption that the bunch length can reach 1.2 cm. Higher luminosity possibility is under study. First frequency map analysis (FMA) is performed on the original BEPCII SR lattice. The result shows that the resonance is really severe in that lattice and the transverse motion of the particles is unstable. Then a new SR lattice is designed to get a large dynamic aperture and much more stable transverse motion. The dynamic aperture of the new lattice including nonlinear wiggler effect is calculated to be very good. This new SR lattice can be used in the commissioning stage of BEPCII.

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