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LATTICE DESIGN FOR BEPCII UPGRADE

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Abstract

The Beijing Electron Positron Collider II (BEPCII) has achieved a series of achievements in high energy physics study. Along with the deepening of the research, more important physics is expected in higher energy region (>2.1 GeV). As the upper limit of BEPCII design energy is 2.1 GeV, an urgent upgrade is required for BEPCII. To achieve a higher luminosity at higher energy, the number of RF cavities is expected to be doubled. In this paper, the lattice design for the upgrade of BEPCII is studied. The modification of the collider layout to accommodate more cavities is introduced. The linear lattice design and the Dynamic Aperture (DA) optimization results will also be shown. The dynamic aperture tracking result show that the lattice could meet the injection requirement of BEPCII beam with reasonable margin.

INTRODUCTION

The Beijing Electron Positron Collider II (BEPCII) [1] is a two-ring electron positron collider which is running in the tau-charm energy region. The upper limit of designed beam energy of BEPCII is 2.1 GeV, with an optimized performance at 1.89 GeV. The commissioning of BEPCII started at the year of 2007, and since then, a series of achievements has been achieved in high energy physics study. Along with the deepening of the research, more important physcis is expected in higher energy region (>2.1 GeV). An urgent upgrade is required for BEPCII to ensure the competitive advantage in high energy physics study [2].

To improve the performance at higher energy, BEPCII is expected to upgrade the RF system from one-cavity to two-cavity per ring, so as to dramatically boost the cavity voltage. The arrangement of elements in BEPCII is very compact, so finding enough space for the extra cavity in each ring is not trivial. In this paper, we show the the layout that successfully provides enough space for two cavities in each ring by modifying the layout of the RF region. The lattice design and the dynamic aperture tracking result in the new layout will be shown.

PARAMETER DESIGN

To minimize the upgradation risk, BEPCII has chosen the classic scheme, which is maintaining the small Pinwinski angle, and raising the beam current and cavity voltage at the same time to achieve a much higher luminosity at higher beam energy. For the upgrade, the machine parameters will be optimized at 2.35 GeV, while the machine is expected to work up to 2.8 GeV.

When optimizing the parameters, the synchrotron radiation power is restricted to 250 kW, the bunch number is limited to 120, the bunch current is kept as low as possible for each cavity voltage. Also, for each cavity voltage, the vertical β function at the IP β_y^* is chosen according to the bunch length, then the coupling of emittances is then chosen according to the beam parameter ξ_{y0}.

The designed parameters at the nominal cavity voltage 3.3 kV and the comparison with the present BEPCII operation parameters at the optimized energy of 2.35 GeV are shown is Table 1 [3]. We can see from Table 1 that, after the upgrade, the luminosity at 2.35 GeV is expected to be tripled in respected to the one obtained during the present BEPCII operation.

Table 1: The Designed Parameters of BEPCII Upgrade (BEPCII-U) and the Comparison with the Present BEPCII Operation Parameters at the Energy of 2.35 GeV

Parameter	BEPCII	BEPCII-Uz
RF voltage [MV]	1.6	3.3
SR power [kW]	110	250
Beam current [mA]	398	900
β_x^*/β_y^*[m]	1.0/0.015	1.0/0.013
Bunch current [mA]	7.1	7.5
Bunch number	56	120
ξ_y	0.029	0.036
Emittance [nm.rad]	147	152
Coupling [%]	0.53	0.35
νs	0.027	0.04
Bucket height	0.0069	0.011
σ_{z0} [cm]	1.54	1.04
σ_z [cm]	1.69	1.3
Peak luminosity [$10^{32}cm^{-2}s^{-1}$]	3.5	11

MODIFICATION OF THE RF REGION

In order to booster the RF voltage from 1.6 MV to 3.3 MV as shown in Table 1, number of RF cavities in each ring of BEPCII collider has to be increased from one to two. The current layout of BEPCII RF region is shown in the upper plot in Fig. 1.

We can see from Fig. 1 that each ring of the BEPCII has one RF cavity on the outer ring. The whole RF region is a dispersive free area in order to avoid the coupling of transverse and longitudinal planes. In order to make space for an extra RF cavity for each ring, and to change the ring layout as little as possible, the quadrupoles in the RF region will be replaced by new ones will smaller sizes and moved

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to the ends of the RF region. The new layout of the RF region with two cavities in each ring is shown in the lower plot in Fig. 1.

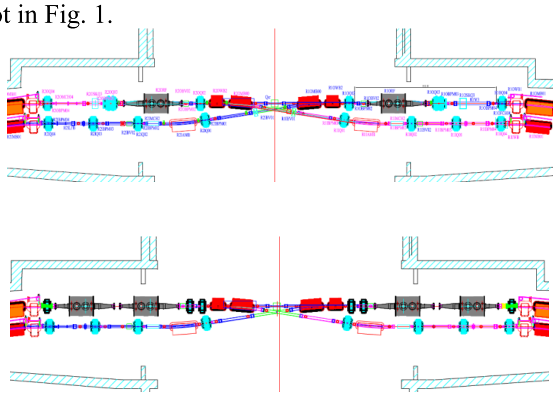

Figure 1: Current and new layout of BEPCII RF region.

The new layout of the RF region is kept the same as the original BEPCII layout as much as possible and saved enough longitudinal space for installing two RF cavities in each ring. The survey and circumference of the new layout of BEPCII is also kept as the original one, which will also benefit the commissioning of the upgrade.

LINEAR LITTICE DESIGN FOR THE UPGRADE

As the layout of the ring is modified, the optics has to be re-matched. The strengths of the quadrupoles are varied to preserve the dispersive free condition, control the beam envelope at the RF cavities, and rematch the lattice to the other part of the ring. Also, as the beam energy is increased, the strengths of the magnets also need to be well controlled during the matching.

The re-matched beam envelope and dispersion function at the RF region is shown in Fig. 2.

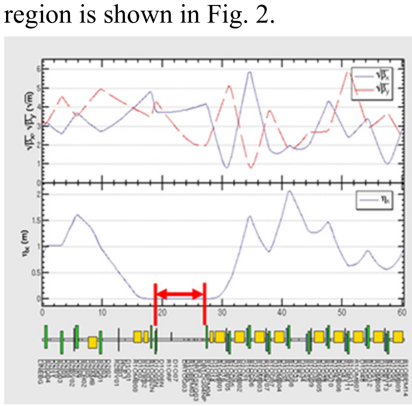

Figure 2: The re-matched beam envelope and dispersion function at the RF region for the electron ring.

We can see from Fig. 2 that the horizontal beam envelope at the RF cavities is kept below 15 m in order to reduce beam loss at the cavities.

In order to match the lattice of the RF region to the rest of the ring, 6 quadrupoles upstream of the RF cavities and 10 quadrupoles downstream of the RF cavities are adjusted. The beam emittance is tried to keep as small as possible during the matching. The re-matched beam envelope and dispersion function for the whole electron ring is shown in Fig. 3.

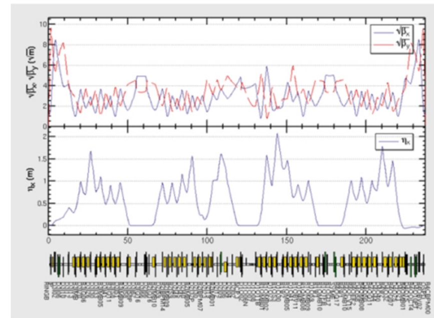

Figure 3: The re-matched beam envelope and dispersion function of the whole ring for the electron ring.

We can see from Fig. 3 that, after the matching, the optics parameters are kept the same as the original BEPCII design, especially the IP and the injection region.

The working points are still chosen to be near the half integer, which were proven to be beneficial for having higher collision luminosity.

The lattice of the positron ring is similarly matched as the electron ring.

DYNAMIC APERTURE OPTIMIZATION

There are 36 sextupoles which are powered with 18 separate power supplies in each ring of BEPCII. These 18 groups of sextupoles are adjusted independently to optimize the dynamic aperture, the tune spread and the $\beta^*_{x,y}$ spread within ±1% energy spread .

The optimized dynamic aperture for the electron ring is shown in Fig. 4.

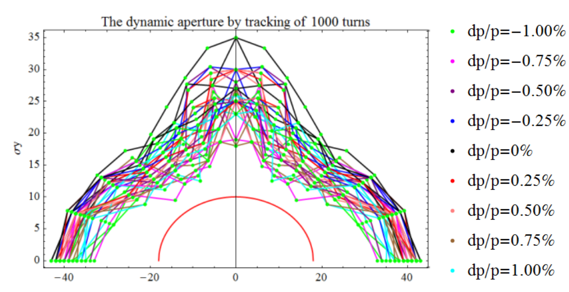

Figure 4: The optimized dynamic aperture for the electron ring.

In Fig. 4, the red ellipse represents the injection requirement of the beam, which is 6 times the injection beam sizes plus 6 times the circulating beam sizes plus the width of septum. The injection requirement is 18σx in horizontal and 10σy in number of the circulating beam.

The lines with different colours in Fig. 3 show the tracking results of particles with different initial phases and with different momentum spread. We can see that the dynamic aperture is 28σx in horizontal and 18σy in vertical plane for momentum spread within ±1%. The dynamic aperture

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of the electron ring is roughly 50% bigger than the injection requirement.

ISSUES AT 2.8 GeV

The current BEPCII, is optimized at 1.89 GeV, and is designed to be able to run up to the energy of 2.1 GeV. Thus, the magnets and power supplies were also designed accordingly. To ensure the lattice could work at 2.35 GeV, as shown in the previous section, the strengths of quadrupoles and sextuples have been limited to the upper limit of the measured data, and we managed to match the lattice without increasing the emittance. But for 2.8 GeV beam energy, the strengths of magnets have to be taken in to consideration seriously.

As for the bending magnets, the ones in the outer ring are designed and manufactured for BEPC, whose designed beam energy is up to 2.8 GeV, so the bending magnets in the outer ring are able to work 2.8 GeV; while the ones in the inner rings are designed and manufactured for BEPCII, whose designed beam energy is up to 2.1 GeV, so the strength of these magnets have to be checked. Simulations with the inner ring bending magnet have been carried out, and it is found that the strength of these magnets could fit the requirement of 2.8 GeV under the condition that the power supplies be replaced. Also, the heat load from the bending magnets of the cooling system will be roughly doubled at 2.8 GeV compared to 2.35 GeV.

For the quadrupoles, about one fourth of the magnets strength has exceed the upper limit of measured excitation curve when the beam energy reaches 2.8 GeV. Also, the excitation curve of the quadrupoles has reaches the saturation region, which limits the further increase of the magnet strength. It is also very hard to replace the quadrupoles with new ones since the number of magnets is big, and it may need to replace the vacuum chamber adjacent to the quadrupoles. So it is decided to replace the power supplies of the quadrupoles and re-match the lattice at 2.8 GeV to lower the strength of quadrupoles. The main outcome of lowering the strength of quadrupoles is that the beam emittance may be increased.

For the sextupoles, we expect the strengths could be lowered to a proper value by optimizing the combination of sextupoles with a stricter upper limit.

The SuperConducting Quadrupole (SCQ), will is used for creating the small βy^* of BEPCII, has also exceeded the quench limit when the beam energy reaches 2.8 GeV. A new SCQ will be designed and manufactured for BEPCII upgrade project. The design is now carrying out in IHEP.

In case that the new SCQ could not be manufactured on time according to the upgrade schedule, a backup scheme with reduced SCQ strength has also been designed. In the new design, the current SCQ could operate at 2.8 GeV, but the collision angle is increased by 2 mrad in order to compensate the geometry change caused by the decrease of bending angle in SCQ with the reduced SCQ strength. The design shows that the dynamic aperture could meet the injection requirement of the ring. The effect of increased crossing angle on background needs to be studied.

Different lattice models for 2.8 GeV will be tested on BEPCII machine to ensure the physics and hardware could work normally at this beam energy.

SUMMARY

An upgrade of BEPCII is planned. The RF voltage will be upgraded from 1.6 MV to 3.3 MV by adding one more cavity in each ring. The luminosity at 2.35 GeV is expected to be tripled after the upgrade compared to the current BEPCII operation luminosity. The layout of the RF region is changed to accommodate two cavities in each ring. A detailed lattice design has been performed accordingly. The dynamic aperture tracking results show that the lattice could meet the injection requirements of BEPCII beam with an extra 50% margin. The strengths of all magnets could meet the requirements at 2.35 GeV.

For the beam energy of 2.8 GeV, the strengths of many magnets have exceeded the upper limit of measurement data. The power supplies will be replaced for the bending magnets in the inner ring in order to fulfil the requirement at 2.8 GeV. New lattice will be designed to reduce the strength of quadrupoles and sextupoles in order for them to work at 2.8 GeV. The current SCQ would exceed the quench limit in order to work at 2.8 GeV, so a new SCQ will be designed and manufactured.

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