DESIGN AND OPTIMIZATION OF THE BEPCII SYNCHROTRON RADIATION MODE*

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Abstract

The upgrade machine of the Beijing Electron-Positron Collider (BEPCII) can be operated not only for high energy physics experiments as a charm factory, but also for the synchrotron radiation users as a first generation light source. The design of the synchrotron radiation (SR) mode of the BEPCII storage ring keeps all the original beam lines of the BEPC. The lattice based on the layout of the collider can meet all the requirements of the SR users, with a rather small emittance. Optimization of the SR mode focuses on reducing the effects from wigglers around the ring and minimizing the emittance. Some results from the operations of the SR mode are also given.

INTRODUCTION ON THE BEPCII

The BEPCII contains a linac, two transport lines and three storage rings. Among them, two rings are in parallel for e- and e+ beams, respectively. It was designed as a factory-like collider at the charm energy region, with a designed luminosity of $1\times10^{33}cm^{-2}s^{-1}$ at the beam energy of 1.89GeV. One machine with two purposes is the most important feature of the BEPCII, which means to provide beam not only for high energy physics experiment, but for synchrotron radiation (SR) users in the dedicated time. The two halves of the outer rings are connected as an SR ring, the third ring named as BSR, with 14 beam lines extracted from 5 wigglers and 9 bending magnets. The layout of the SR mode of BEPCII is given in Fig. 1, in which the beam lines from wigglers and bends are marked.

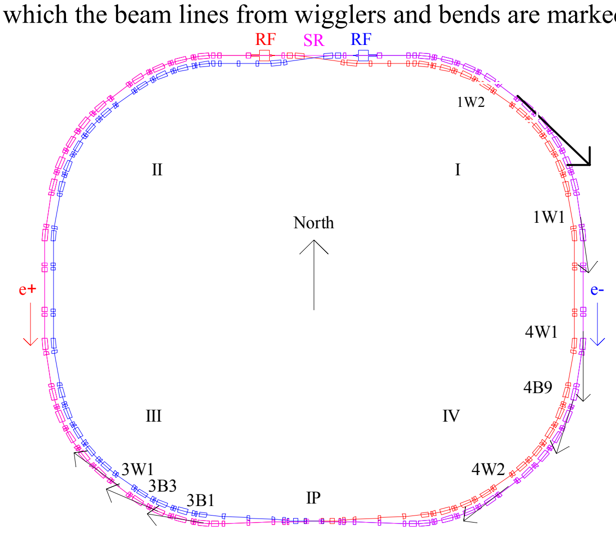

Figure 1: Layout of the BEPCII storage rings and beam lines extracted from wigglers and dipoles.

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In the interaction region (IR), two dipole coils in the superconducting quadrupoles near the interaction point (IP) to bend the electron beam from one outer half-ring to another. The beam energy of the dedicated SR mode of the BEPCII is 2.5 GeV, which is ~1/3 higher than the collision mode. The designed beam current is 250 mA with a beam lifetime of 10 hrs when all wigglers closed.

The detailed description of the BEPCII and the collision at the BEPCII for high energy physics can be found in Ref. [1] and [2]. Here we focus on the design of the SR mode and the optimization during operation.

DESIGN OF THE SR MODE

BEPCII is a factory-like collider, so the lattice structure was designed for a quite large emittance for high collision beam current. Each arc of the BEPCII storage rings has 12 quasi-FODO cells, with two missing dipoles in the 2nd and 6th cells, respectively, to enlarge the emittance of the collision mode. This brings the difficulty to the design of the SR mode, since a quite small emittance is required for any SR lattice. The higher beam energy of the SR mode also limits the quadrupoles' strength to reduce the beam emittance. A small quadrupole was added at the center of the north "bridge", which connected the two half-rings at the RF region, to make the lattice more flexible. A symmetric lattice with the superperiod number of 2 was designed with the Twiss functions shown in Fig. 2. The two half-rings have the same Twiss functions, and are partially symmetric in the injection region. To get a small emittance, non-dispersion free lattice was applied. The beta functions at the wigglers 4W2 and 3W1 are squeezed as small as possible to keep an enough beam lifetime. Table 1 lists the main parameters of the SR mode.

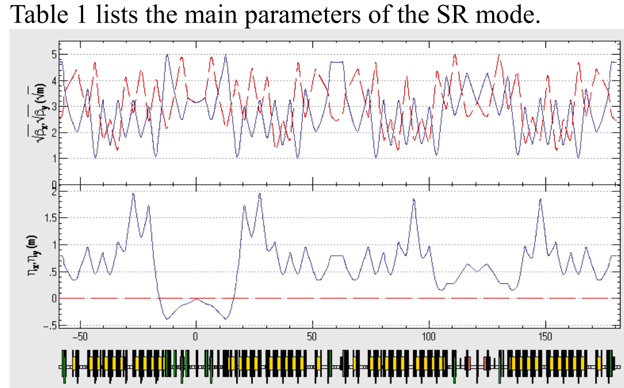

Figure 2: Twiss functions (upper: $\beta_{x,y}$, lower: $\eta_{x,y}$).

Four families of sextupoles were used to correct the natural chromaticity. The sextupoles' families are interleaved powered as SD1, SF1, SD2, SF2, SD1, SF1, SD2, SF2 and SD1 from the IP to the injection point in each arc. Here SD and SF stand for defocusing and focusing sextupoles, respectively. The transverse chromaticities were corrected to 1.0 to avoid the head-tail instability. Considering seriously the higher order chromaticities and anharmonicities, we optimized the strengths of sextupoles to obtain a quite large dynamic aperture with MAD [3].

Table 1: Main Parameters of the SR Mode in BEPCII

Beam energy	GeV	2.5
Circumference	m	241.13
RF frequency	MHz	499.8
Harmonic number		402
Energy loss per turn	keV	336
Beam current	mA	250
Damping time (x/y/s)	ms	12/12/6
Natural momentum spread		6.66×10^{-4}
Momentum compaction		0.0185
Tunes (x/y/s)		7.28/5.18/0.026
Natural chromaticity		-10.3/-10.1
Natural horizontal emittance	nm	147

Figure 3 shows the variations of transverse tunes as functions of momentum deviation. With all the wigglers being closed, the vertical tune will be increased ~0.08, and the emittance will have 10% enhancement. The dynamic apertures with and without wigglers are shown in Fig. 4. Magnetic errors are not considered in the dynamic aperture estimation.

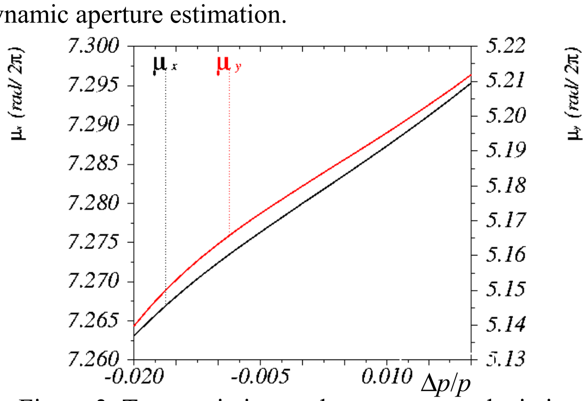

Figure 3: Tune variation as the momentum deviation.

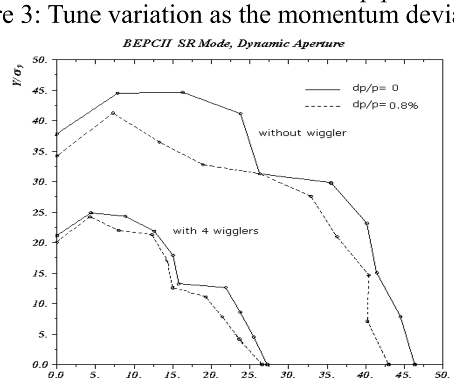

Figure 4: Dynamic aperture with and without wigglers.

OPERATION OF THE SR MODE

Since the end of 2006, the BEPCII had delivered beam to the users with its dedicated SR mode for more than 5 months, besides the luminosity commissioning. In March 2008, the design values of beam energy, current and lifetime were reached. In the meantime, the full energy injection was realized, which promoted the efficiency of operation greatly. Figure 5 shows the beam status in a one-day operation as an example. Five wigglers are used in the normal operation. Table 2 lists the main parameters of the wigglers used in the dedicated SR mode of the BEPCII.

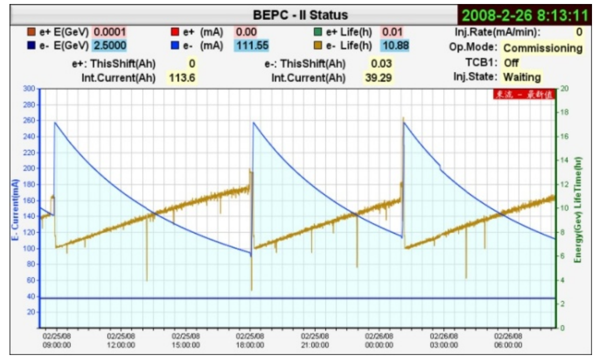

Figure 5: One-day operation of the SR mode of BEPCII.

Table 2: Parameters of Wigglers Used in the SR Mode

	1W1/1W2	4W2	3W1	4W1
Period Number	7	11	5	1
Period length (mm)	228	148	300	1360
Gap (mm)	41	15	43	66
Field (T)	1.2	1.8	1.4	1.8
K value	27.2	25.7	39.8	229
E_c (keV)	5.32	7.73	5.90	7.48

OPTIMIZATION OF THE SR MODE

Since the emittance of the operational mode is not small enough, and the beam lifetime during the running of SR mode is not as good as expected, it is necessary to have the SR mode optimized. The philosophy to optimize the lattice is to minimize the H function ($H=\gamma\eta_x^2+2\alpha\eta_x\eta_x'+\beta\eta_x'^2$) around the ring, with the non-dispersion free style. The transverse tunes were then adjusted to the region of ν_x/ν_y ~ 7.7/4.7. The maximum and minimum β functions around the ring were controlled to be less than 25m and greater than 1m, respectively. The Twiss functions at the exits of the beam lines were restricted by the requirements of the SR users. Figure 6 shows the Twiss functions of the new lattice of the SR mode. The 2-fold symmetry is still kept, and the horizontal dispersion is kept to be less than 1.5 m around the ring.

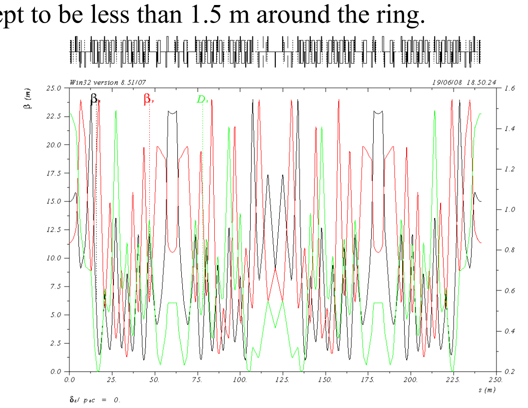
Figure 6: Twiss functions of the optimized SR mode.

Table 3 gives the main parameters of the optimized SR mode with the comparison of the current lattice. Figure 7 compares the H functions at each dipole around the ring of the optimized mode and the original SR mode.

Table 3: Main Parameters of the Optimized Lattice and Comparison with the Original Lattice

Mode	Original	Optimized
Tunes ν_x/ν_y	7.28/5.18	7.72/4.75
$<H>$ @dipole (m)	0.14	0.090
Momentum comp.	0.0186	0.0137
Natural chromaticity, x/y	-9.04/-8.95	-9.81/-8.30
Max. β_x/β_y (m)	22.9/25.0	24.0/24.0
$<\eta_x>$ around ring (m)	0.795	0.724
β_x/β_y@inj. point (m)	22.7/14.6	22.8/10.6
η_x@inj. point (m)	0.746	0.538
β_x/β_y@RF cavity (m)	10.9/16.3	11.3/14.3
η_x@RF cavity (m)	0.265	0.400
β_x/β_y @4W1 (m)	10.6/24.5	11.0/18.8
β_x/β_y @4W2 (m)	5.15/3.35	6.40/ 4.96
β_x/β_y @1W1 (m)	7.60/8.61	6.74/ 11.7
β_x/β_y @1W2 (m)	4.99/2.17	5.74/ 3.51
β_x/β_y @3W1 (m)	6.83/3.49	10.4/ 3.51
Hori. nat. emittance(nm)	147	84.5

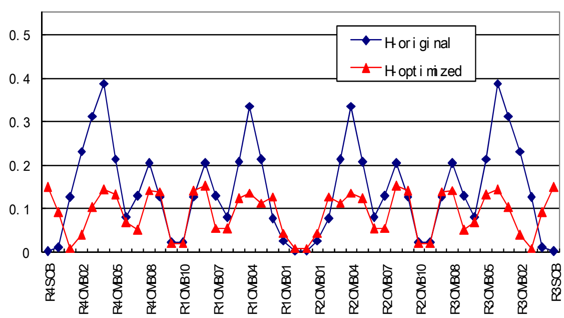

Figure 7: H function at the dipoles around the ring.

The non-linear lattice, say the lattice with sextupoles, was matched with the chromaticity corrected to 1. Four families of sextupoles were applied to correct the 1st and 2nd order chromaticities. The 4 families of sextupoles are interleaved powered as that of the original mode, but with one SF missing, which are SD1, 0, SD2, SF1, SD2 , SF2, SD1, SF1, SD2 in one quadrant from the IP or NCP to the injection point. Figure 8 shows the tune variations of the optimized mode as functions of momentum deviation.

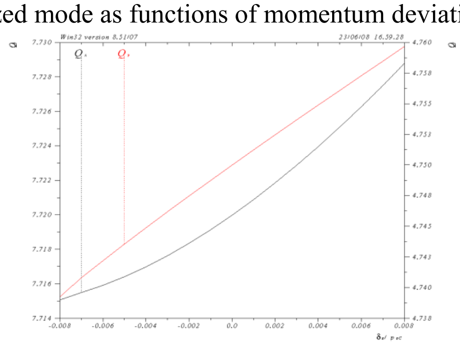

Figure 8: Tune variation as momentum deviation for the optimized SR mode.

The frequency map analysis (FMA) is applied to optimize the dynamic aperture of the bare lattice [4]. Figure 9 shows the results of FMA, and Fig. 10 gives the dynamic aperture of the optimized SR lattice. The dynamic apertures of the off-momentum particle, reached $42\sigma_x\times42\sigma_y$@$\pm14\sigma_e$, which are larger than the requirement of injection. The magnetic errors will reduce the dynamic aperture ~5σ in transverse as the previous experiences.

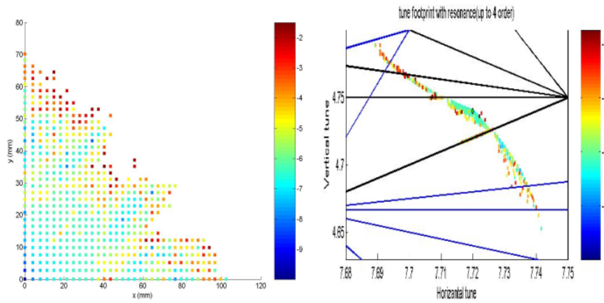

Figure 9: FMA results of the optimized SR lattice.

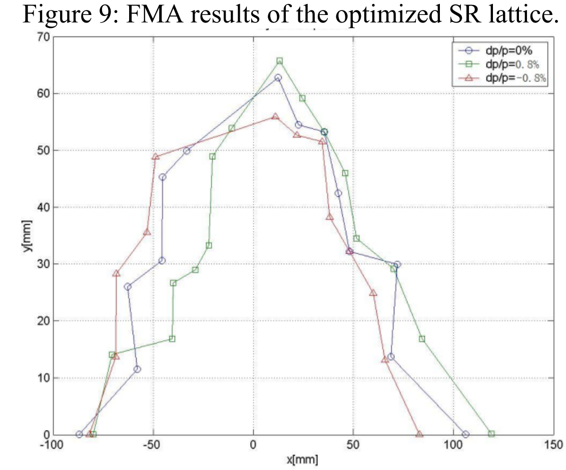

Figure 10: Dynamic aperture at the IP of the ring.

SUMMARY

The dedicated synchrotron radiation mode of the BEPCII was designed at the energy of 2.5 GeV, based on the lattice layout of the collision mode. The SR mode was commissioned from 2006, and has successfully provided the dedicated synchrotron light to the users from 2007. The operation of the SR mode with all the wigglers on was quite well. To achieve a rather small emittance, the SR mode was optimized with minimizing the H function around the ring. The new lattice fits all the requirements of the insertion magnets and dynamic aperture, and the emittance was reduced ~40%. The preliminary running with the new lattice gave us confidence for further study. It is expected to replace the old SR lattice in the future.

REFERENCES

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