ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-WEPAB033

LATTICE DESIGN OF THE CEPC COLLIDER RING FOR A HIGH LUMINOSITY SCHEME*

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Abstract

A high luminosity scheme of the CEPC has been proposed aiming to increase the luminosity mainly at Higgs and Z modes. In this paper, the high luminosity scheme will be introduced briefly, including the beam parameters and RF staging. Then, the lattice design of the CEPC collider ring for the high luminosity scheme will be presented, including the bare lattice design and dynamic aperture optimization at Higgs energy.

INTRODUCTION

The Cicular Electron and Positron Collider (CEPC) [1] is a double ring collider with two interaction points. The layout of the CEPC accelerator complex is shown in the Fig. 1. The lattice of the collider ring was designed with the following requirements:

- Double ring, 100 km, 2 interaction points (IPs).
- SR power limit to 30 MW (50 MW upgradable).
- Higgs mode hold the first priority and compatible with the ttbar/W/Z modes.
- Compatible with the Super Proton Proton Colider (SPPC) in a common arc tunnel.
- Interaction region: crab waist collision, local chromaticity correction, asymmetric.
- ARC region: dual aperture dipole and quadrupole magnets, non-interleaved sextupoles.
- RF region: shared cavities for two beam @ ttbar/H.
- Injection region: on-axis injection for Higgs mode and off-axis injection for other modes.
- Correction of the sawtooth orbit.
- Spin polarized beam @ Z.

A conceptual design has been made for the luminosity goal $3/10 \times 10^{34}/\mathrm{cm}^2/\mathrm{s}$ for Higgs/W at 30 MW and $32 \times 10^{34}/\mathrm{cm}^2/\mathrm{s}$ for Z at 16.5 MW [1]. To mainly increase the luminosity at the Higgs and Z energy, a high luminosity scheme [2] of the CEPC has been proposed mainly by squeezing the vertical beta function at IP, emittance and increasing the beam current at Z. In the following, the beam parameters for all the four modes and a new RF staging scheme will be presented, then the lattice design and dynamic aperture at

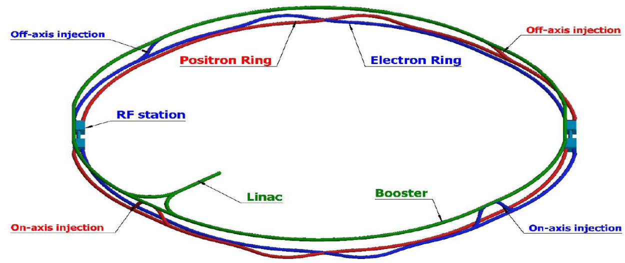

Figure 1: Layout of CEPC accelerator complex.

Higgs [3]. The optimization of dynamic aperture at other modes is undergoing.

BEAM PARAMETERS

The beam parameters for the ttbar/Higgs/W/Z modes are listed in the Fig. 2.

For the Higgs energy running, the vertical beta function at IP β_y^* has been squeezed from 1.5 mm to 1.0 mm and emittance from 1.21 nm to 0.64 nm while the single bunch population N_e decreased a bit from 15×10^{10} to 14×10^{10} in order to control the energy acceptance requirment. The beam-beam simulation with the Higgs parameters listed in the Fig. 2 gave a luminosity of $5.0 \times 10^{34}/\mathrm{cm}^2/\mathrm{s}$ [4].

For the Z energy running, the beam current has been almost doubled as the high order mode problem can be solved by using the high current 1-cell cavities. Larger momentum compaction factor α_p, emittance ϵ_x and longitudinal tune Q_s are favourate to suppress the microwave and transver mode coupling instability [5] and to increase stable tune area which shrink when considering both the beam-beam effect and longitudinal impedance [4]. Thus, the phase advance of arc cell was reduced from 90 degrees (for Higgs/ttbar) to 60 degrees.

For the W energy running, the phase advance was reduced as Z to increase the stable tune area.

For the ttbar energy running, the luminosity has not been pushed to a high value. An asymmetric acceptance [6] is required in lattice design as the asymmetric energy distribution due to strong synchrotron radiation.

RF STAGING

A new RF staging was proposed for the high luminosity scheme [7]. The design philosophy is holding the Higgs running and flexible switching first priority, keeping low

* Work supported by the National Key Programme for S&T Research and Development (Grant No. 2016YFA0400400),Key Research Program of Frontier Sciences, CAS, Grant No. QYZDJ-SSW-SLH004, and CAS Center for Excellence in Particle Physics (CCEPP).
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	ttbar	Higgs	W	Z
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	30			
Half crossing angle at IP [mrad]	16.5			
Bending radius [km]	10.7			
Energy [GeV]	180	120	80	45.5
Energy loss per turn [GeV]	9.1	1.8	0.357	0.037
Piwinski angle	1.21	5.94	6.08	24.68
Bunch number	35	249	1297	11951
Bunch population [10^10]	20	14	13.5	14
Beam current [mA]	3.3	16.7	84.1	803.5
Momentum compaction [10^-5]	0.71	0.71	1.43	1.43
Beta functions at IP (bx/by) [m/mm]	1.04/2.7	0.33/1	0.21/1	0.13/0.9
Emittance (ex/ey) [nm/pm]	1.4/4.7	0.64/1.3	0.87/1.7	0.27/1.4
Beam size at IP (sigx/sigy) [um/nm]	39/113	15/36	13/42	6/35
Bunch length (SR/total) [mm]	2.2/2.9	2.3/3.9	2.5/4.9	2.5/8.7
Energy spread (SR/total) [%]	0.15/0.20	0.10/0.17	0.07/0.14	0.04/0.13
Energy acceptance (DA/RF) [%]	2.3/2.6	1.7/2.2	1.2/2.5	1.3/1.7
Beam-beam parameters (ksix/ksiy)	0.071/0.1	0.015/0.11	0.012/0.113	0.004/0.127
RF voltage [GV]	10	2.2	0.7	0.12
RF frequency [MHz]	650	650	650	650
HOM power per cavity (5/2/1cell)[kw]	0.4/0.2/0.1	1/0.4/0.2	-/1.8/0.9	-/-/5.8
Longitudinal tune Qs	0.078	0.049	0.062	0.035
Beam lifetime (bhabha/beamstrahlung)[min]	81/23	39/40	60/700	80/18000
Beam lifetime total [min]	18	20	55	80
Hour glass Factor	0.89	0.9	0.9	0.97
Luminosity per IP[1e34/cm^2/s]	0.5	5.0	16	115

Figure 2: Beam parameter of the CEPC collider ring [8, 9].

cost at early stage and getting high luminosity for all modes. The three stages are shown in the Fig. 3: In stage 1, the layout and parameters are the same with the CDR except a longer central part. It get high luminosity at Higgs and medium or low luminosity at Z. In stage 2, the Higgs cavities are moved to the center and high current Z cavities are added. The low current Higgs cavities are bypassed when running at Z. It get high luminosity at Z. In stage 3, the low current, high gradient and high Q cavities will be added for ttbar running.

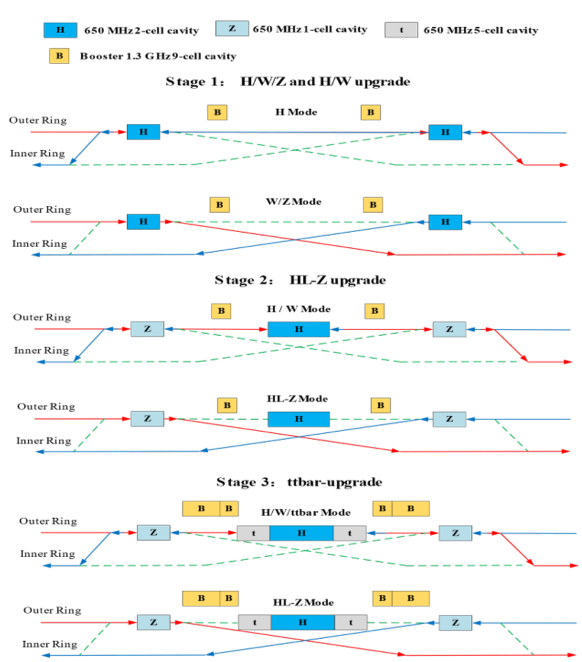

Figure 3: A new RF staging for the high luminosity scheme [7].

LATTICE DESIGN AT HIGGS ENERGY

Interaction Region

To make the lattice robust and provide a good start point for dynamic aperture optimization, the the length from IP to the first quadrupole L^* is reduced from 2.2 m to 1.9 m [2, 3]. The space in the final doublet cryo-module is used without changing the front-end position of the cryo-module, i.e. not affectting the detector design.

The dynamic aperture reduction due to the synchrotron radiation damping and fluctuation due to quadrupole is significant especially on the vertical plane [10]. The synchrotron radiation power of beam due to the betatron motion in quadrupole proportional to $\sum(K_1 l)^2\beta/l$, where β, K_1 and l are the beta function at quadrupoles, the normalized strength and the length of quadrupoles respectively. The normalized strength and vertical beta function of final quadrupole Q1 is largest in the ring thus the contribution of th Q1 dominant. A longer Q1 will significantly decreased the power on vertical plane and thus help to increase the dynamic aperture. The length of Q1 has been increased from 2 m to 2.5 m to ease the quadrupole radiation effect. To further ease the quadrupole radiation effect, the Q1 was devided into two equal-length quarupoles and the strength of second one is lower as larger vertical beta function [11]. The comparison of the final doublet parameter is shown as following: For CDR: L^* = 2.2 m, LQ1 = 2.0 m, LQ2 = 1.5 m, d = 0.3 m, GQ1 = 136 T/m, GQ2 = 111 T/m; For the High luminosity scheme: L^* = 1.9 m, LQ1A = 1.22 m, LQ1B = 1.22 m, LQ2 = 1.5 m, d = 0.3 m, GQ1A = 142 T/m, GQ1B = 96 T/m, GQ2 = 56 T/m. The lattice of the interaction region are shown is Fig. 4.

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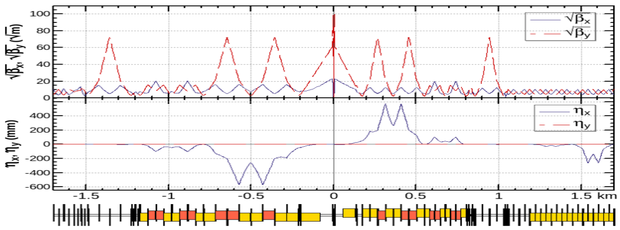

Figure 4: The interaction region lattice for the high luminosity scheme at Higgs.

Arc Region

A shorter cell length was used to squeeze the emittance from 1.2 nm to 0.64 nm. To increase the bend filling factor, the layout of the sextupoles in two rings were changed from staggered to parallel and the left drifts are used for a longer bend. The length of arc quadrupole are increased from 2 m to 3 m for the optimization of the quadrupole radiation effect.

The 2nd order chromaticity is a main aberration for the optimization of momentum acceptance with 2-repeated non-interleaved sextupole structure [6] which used in the CDR. A period with 2-repeated sextupole scheme is shown in the upper plot of Fig. 5. In the CDR lattice, 2nd order chromaticity generated in the ARC region was corrected with the IR knobs of phase advance or weak quadrupole at the first image point. However, the IR knobs generate distortions at IP (beta, alpha and dispersion functions) especially for the horizontal plane. A 8-repeated sextupoles structure generates much less 2nd order chromaticity for the horizontal plane [12] as the coupling term disppeared. Actually, a 4-repeated sextupoles structure, shown in the lower plot of Fig. 5, give an almost same result and not too sensitive to the errors as less repeated sextupoles.

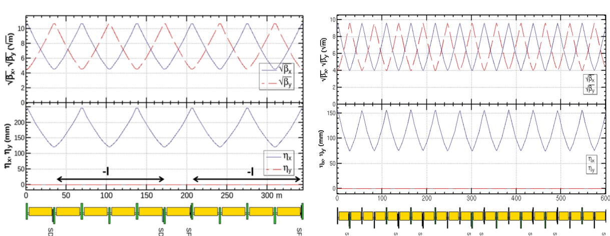

Figure 5: Periods with 2 and 4 (upper and lower) repeated sextupole scheme.

The comparison of the energy dependent tune shift with the 2 and 4 repeated sextupole structure are shown in Fig. 6. Both of them contain around 180 FODO cells. The 2nd order chromaticity with only 2 families of sextupoles has been reduced from 313/410 to 8/139 (x/y).

RF Region

To increase the bend filling factor, shorter phase tuning sections were used in the RF region.

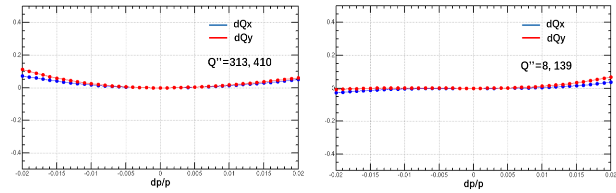

Figure 6: Energy dependent tune shift with the 2 and 4 (upper and lower) repeated sextupole scheme.

DYNAMIC APERTURE AT HIGGS ENERGY

The dynamic aperture was further optimized with an algorithm based on the Multi-Objective Differential Evolution (MODE) [13, 14]. Totally, 32 families of the arc sextupoles, 8 families of the IR sextupoles, 4 families of mulipoles and 8 phase advance tunning knobs were used as variables. The objectives were to maxmize both the whole DA area and the large-off-momentum DA area in x-/delta plane while constaintting the energy- and amplitue- dependent tune shifts. The particle tracking was done with one damping time and included synchrotron motion, radiation damping, radiation fluctuation and correction of sawtooth orbit [6]. The dynamic aperture without error at Higgs energy acheived $16\sigma_x \times 32\sigma_x \times 1.9\%$, shown in the Fig. 7, which fulfills the requirements of injection and beam-beam and has left enough margin for the error effects.

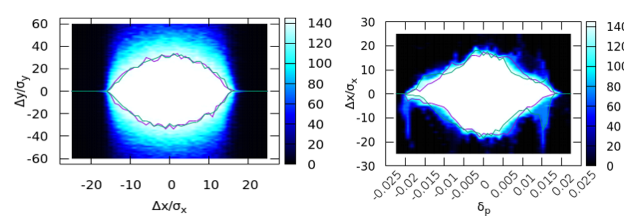

Figure 7: Dynamic aperture w/o errors at Higgs energy for the on- and off- (upper and lower) momentum particles [15].

SUMMARY

The beam parameter and RF staging of the four modes for the high luminosity scheme were studied. The high luminosity lattice of CEPC collider ring with luminosity goal $5 \times 10^{34}/\mathrm{cm}^2/\mathrm{s}$ and SR radiation power limit 30 MW @Higgs has been designed by mainly squeezing the vertical beta function at IP and emittance. The length from IP to the first quadrupole was reduced from 2.2 m to 1.9 m and the synchrotron radiation effect of the final doublet was optimized. A new chromaticity correction scheme was used in the ARC region. Dynamic aperture without error at Higgs energy fulfills the requirements.

More work need to be done for the high luminosity scheme, inclduding dynamic aperture for the other modes, error corretion and so on.

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