DESIGN STUDY ON CEPC POSITRON DAMPING RING AND BUNCH COMPRESSOR *

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Abstract

The primary purpose of CEPC damping ring is to reduce the transverse phase spaces of positron beam to suitably small value at the beginning of linac and also adjust the time structure of positron beam for reinjection into the Linac. Longitudinal bunch length control was provided to minimize wake field effects in the linac by a bunch compressor system after the damping ring. Both designs for damping ring and bunch compressor were discussed in this paper.

INTRODUCTION

So far, the whole CEPC system is composed of three parts: a linac, a booster, the main collider ring [1, 2]. The linac injector system is composed of a 10 Gev S-band linac with electron/positron source and a 1.1 Gev damping ring (a linac injector scheme without damping ring is also proposed and studied).

The first part of the injector is a normal conducting S-band linac with frequency in 2856.75 MHz and provides electrons and positrons at energy up to 10 Gev. The main parameters are shown in Table 1.

Table 1: Main Parameters of CEPC Linac

Parameter	Symbol	Unit	Value
e^-/e^+ beam energy	E_e^-/E_e^+	GeV	10
Repetition rate	f	Hz	50
e^-/e^+ bunch population	N_e^-/N_e^+		6.25×10^9
	N_e^-/N_e^+	nC	1.0
Energy spread (e^-/e^+)	σ_E		$<2\times10^{-3}$
Emittance (e^-/e^+)		mm mrad	<0.3
e^- beam energy on Target		Gev	4
e^- bunch charge on Target		nC	10

The repetition rate is 50 Hz and one-bunch-per-pulse is considered. The linac contains electron linac and positron linac. To achive 1.0 nC per bunch positron beam, a 4 Gev primary electron beam with bunch charge in 10 nC hit tungsten target. The large transverse emittance of the positron beam emerging from the target is transformed to match pre-accelerating section with AMD flux concentrator. The captured positron beam will be pre-accelerated to 200 Mev and then transported back to the beginning of main linac. Considering the time schedule and to make the positron beam emittance small, a damping ring is necessary.

The positron beam are accelerated up to 1.1 Gev with about 20 S-band accelerating tubes without SLED and extacted to damping ring, then the positron beam are extacted and accelerated up to 10 Gev at next pulse. The section form 200 Mev to 1.1 Gev can not use SLED and the average gradient is 18 MV/m. For high energy part form 1.1 Gev to 4 Gev and further to 10 Gev the accelerating gradient is about 27 MV/m, maybe can reach 30 MV/m. The layout of CEPC accelerator chain is shown in Fig. 1.

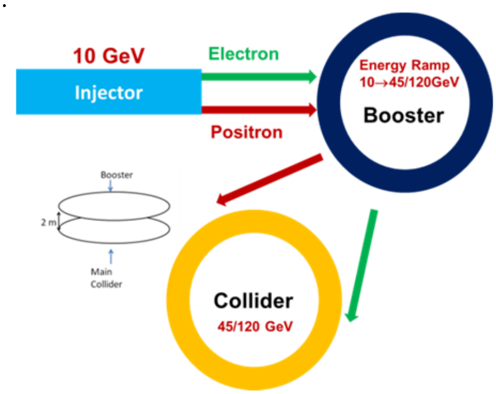

Figure 1: Sketch of CEPC accelerator chain.

Further, longitudinal bunch length control must be provided to minimize wake field effects in the linac. Reducing bunch length in the ring to the required value will need very high (~40 MV) RF voltage, so we add a bunch compressor system after the damping ring.

DAMPING RING DESIGN

The energy of DR is 1.1 Gev and the circumference is 58.5 m. The DR has a racetrack shape and the arcs were designed with 60 degree FODO cell.

The injected emittance (normalized) for DR is 3500 mm·mrad and the injected energy spread is about 0.25%. The positron beam will be storaged in DR for 20 ms according to the 5 Hz repetition rate for the linac. Then the positron bunch will be extracted. The requirement for the extracted energy spread is lower than 0.1%. The extracted emittance is better to be smaller than half of the injected emittance. Considering the issue of injection efficiency, we hope the transverse acceptance of DR to be larger than three times of the injection beam size.

DR Parameter Design

- Damping time

$$U_0 = 88.5\times10^3 \frac{E_0^4(GeV)}{\rho(m)} \tag{1}$$

$$\tau_{x,y} = \frac{2E_0T_0}{U_0} \tag{2}$$

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The principle of CEPC damping ring is shown in Fig. 2.

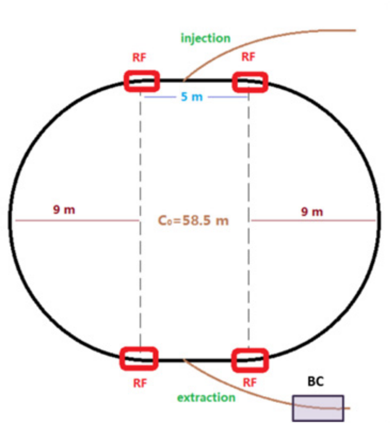

Figure 2: Layout of CEPC damping ring.

$$\tau_z = \frac{E_0 T_0}{U_0} \tag{3}$$

- Nature emittance

$$\varepsilon_x = \frac{C_q \gamma^2 \varphi^3 \left(1 - \frac{3}{4}\sin^2\left(\frac{\mu}{2}\right) + \frac{1}{60}\sin^4\left(\frac{\mu}{2}\right)\right)}{8 J_x \sin^3\left(\frac{\mu}{2}\right)\cos\left(\frac{\mu}{2}\right)} \tag{4}$$

where μ is the phase advance for the FODO cell and φ is the bending angle per cell. Furthermore, one can make an estimation of the momentum compaction factor.

$$\alpha_p = \left(\frac{\varphi}{2}\right)^2 \left(\frac{1}{sin^2 \frac{\mu}{2}} - \frac{1}{12}\right) \tag{5}$$

- Quadrupole strength

$$\cos\mu_x = 1 - \frac{L^2}{2f^2} \tag{6}$$

$$f = \frac{1}{K l_q} \tag{7}$$

- Extracted emittance and energy spread

$$\varepsilon_{x,ext} = \varepsilon_{inj}\exp\left(-2\tau/\tau_x\right) + \varepsilon_0\left[1 - \exp\left(-2\tau/\tau_x\right)\right] \tag{8}$$

$$\varepsilon_{y,ext} = \varepsilon_{inj}\exp\left(-2\tau/\tau_y\right) \tag{9}$$

$$\delta_{ext} = \delta_{inj}\exp\left(-2\tau/\tau_z\right) + \delta_0\left[1 - \exp\left(-2\tau/\tau_z\right)\right] \tag{10}$$

- RF parameters

$$U_0 = eV_{rf}\sin\phi_s \tag{11}$$

$$\sigma_{z0} = \sqrt{-\frac{2\pi E_0 \alpha_p}{f_{rf} T_0 e V_{rf}\cos\phi_s}}\bar{R}\delta_0 \tag{12}$$

$$\eta_{RF} = \sqrt{\frac{2U_0}{\pi\alpha_p f_{rf} T_0 E_0}\left(\sqrt{q^2 - 1} - \arccos\left(\frac{1}{q}\right)\right)} \quad \left(q = \frac{eV_{rf}}{U_0}\right) \tag{13}$$

The main parameters of damping ring are listed in Table 2.

Table 2: Main Parameters of Damping Ring.

	DR V1.0
Energy (Gev)	1.1
Circumference (m)	58.5
Bending radius (m)	3.6
Dipole strength B_0 (T)	1.01
U_0 (kev/turn)	35.8
Damping time x/y/z (ms)	12/12/6
δ_0 (%)	0.049
ε_0 (mm.mrad)	302
Nature σ_z (mm)	7 (23ps)
Extract σ_z (mm)	7 (23ps)
ε_{inj} (mm.mrad)	3500
$\varepsilon_{ext\ x/y}$ (mm.mrad)	434/145
$\delta_{inj}/\delta_{ext}$ (%)	0.25 /0.05
Energy acceptance by RF(%)	1.0
f_{RF} (MHz)	650
V_{RF} (MV)	1.8

DR Optics Design

We chose 60°/60° FODO cell and interleave sextupole scheme for the arc. The emittance of the ring is 140 nm. The twiss parameters of DR are shown in Figs. 3-5.

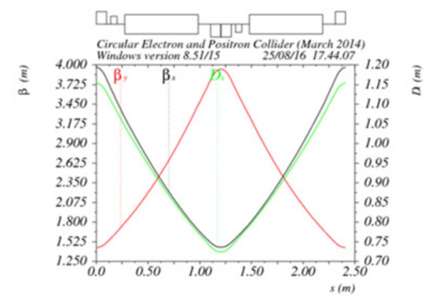

Figure 3: Twiss parameter for the arc FODO cell.

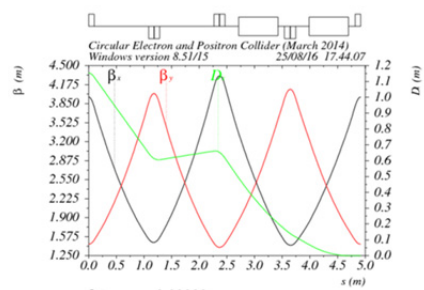

Figure 4: Twiss parameter for the dispersion suppressor.

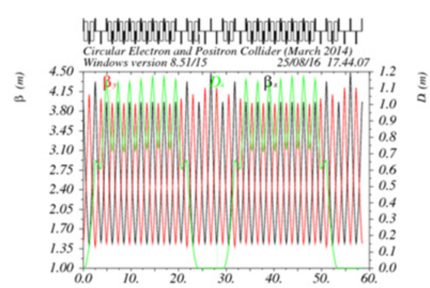

Figure 5: Twiss parameter for the whole ring.

Dynamic Aperture of DR

The chromaticity of the damping ring was corrected by two sextupole families. Then we tracked the DA of damping ring by 240000 turns (4 damping times) using SAD. The DA result is shown in Fig. 6. Since the DA is much larger than 5 times of injection beam size, the injection acceptance for the damping ring should be no problem.

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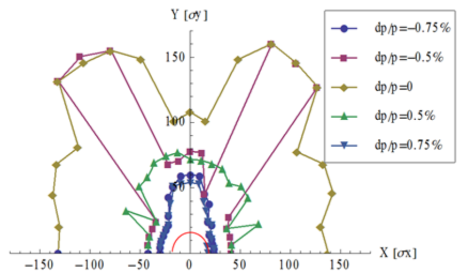

Figure 6: DA of damping ring (red line: 5 times of injection beam size).

BUNCH COMPRESSOR DESIGN

After damping ring, the longitudinal bunch length control must be provided to minimize the wake field effects in the linac. Reducing bunch length in the ring to the required value will need very high (~40 MV) RF voltage, so we add a bunch compressor system after the damping ring. The bunch length will be reduced by about 4 times through the bunch compressor. While the process of bunch compressing is at the cost of enlarging the beam energy spread at the exit of bunch compressor.

Consideration for BC Design

The injection energy for bunch compressor is 1.1 Gev, injection bunch length is 7 mm, and the injection energy spread is 0.05%. After the bunch compressor, the beam energy should keep almost 1.1 Gev and the bunch length should be smaller than 3 mm in order to be accelerated in the linac. We need to decide the value of the extraction bunch length and energy spread. Meanwhile the compression ratio for BC is better to be flexible. The primary structure of bunch compressor in our mind is shown in Fig. 7.

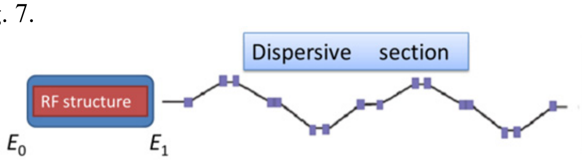

Figure 7: Principle sketch of bunch compressor.

We used following formulas to calculate the parameters for BC:

$$R_{56}R_{66} = -\frac{\sigma_1}{\delta_0} \tag{14}$$

$$R_{66} = \frac{E_0}{E_1} \tag{15}$$

$$R_{56} = R_{56}R_{66} / R_{66} \tag{16}$$

$$\delta_1 = \frac{\sigma_0}{R_{56}} \tag{17}$$

$$V_{rf} = \sqrt{(E_1 - E_0)^2 + \left(\frac{E_1}{R_{56}k_{rf}}\right)^2} \quad \left(k_{rf} = \frac{2 f_{rf}}{c}\right) \tag{18}$$

$$tg\phi_{rf} = -\frac{E_1}{R_{56}k_{rf}(E_1 - E_0)} \Rightarrow \phi_{rf} \tag{19}$$

Primary Parameter Choice for BC

The primary parameter designs for BC are listed in table 3. Also we studied the relationship of extracted energy spread and RF voltage with different final bunch length (shown in Figs. 8-9).

Table 3. Parameters of CEPC Bunch Compressor.

	BC (case I)	BC (case II)
E_0 (Gev)	1.1	
δ_0 (%)	0.05	
σ_{z0} (mm)	7	
f_{RF} (MHz)	2856	
V_{RF} (MV)	14.5	19.3
ϕ_{RF} (degree)	86	87
R_{56} (m)	-4	-3
E_f (Gev)	1.101	1.101
δ_f (%)	0.17	0.23
σ_{zf} (mm)	2 (6.7ps)	1.5 (5ps)

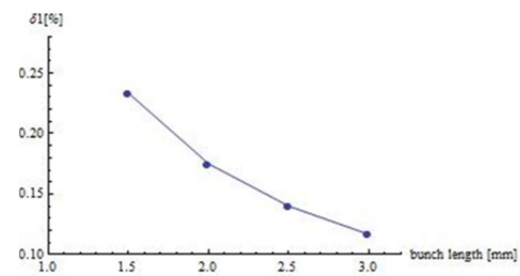

Figure 8: BC extracted energy spread vs. bunch length.

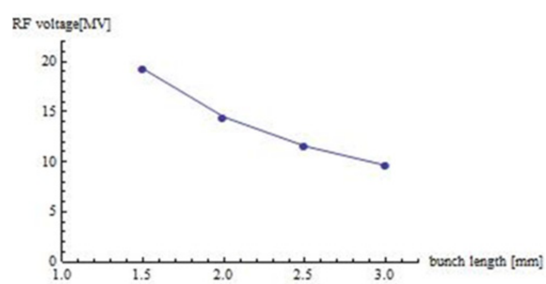

Figure 9: BC RF voltage vs. bunch length.

SUMMARY

The primary purpose of CEPC damping ring is to adjust the time structure of positron beam for reinjection into the linac and reduce the transverse phase spaces of positron beam to suitably small value at the beginning of linac. Primary DR design has been finished. DA can fulfil the requirement for injection. Reducing bunch length in the ring to the required value will be too costly, so we add a bunch compressor system after the damping ring. Primary parameter design for BC has been given. The detail optics design and beam dynamics study is underway.

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REFERENCES

[1] The CEPC-SPPC Study Group, "CEPC-SPPC preliminary Conceptual Design Report", Volume II- Accelerator, IHEP-CEPC-DR-2015-01, IHEP-AC-2015-01, March 2015.

[2] The CEPC-SPPC Study Group, CEPC-SPPC Progress Report, Accelerator 2015-2016, IHEP-CEPC-DR 2017-01, IHEP-AC-2017-01, April, 2017.

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