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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>e⁻ / e⁺ beam energy</td>
<td>Eₑ⁻/Eₑ⁺</td>
<td>GeV</td>
<td>10</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>f</td>
<td>Hz</td>
<td>50</td>
</tr>
<tr>
<td>e⁻ / e⁺ bunch population</td>
<td>Nₑ⁻/Nₑ⁺</td>
<td>nC</td>
<td>1.0</td>
</tr>
<tr>
<td>Energy spread (e⁻ / e⁺)</td>
<td>σₑ</td>
<td>mm</td>
<td>&lt;2×10⁻³</td>
</tr>
<tr>
<td>Emittance (e⁻ / e⁺)</td>
<td></td>
<td>mm-rad</td>
<td>&lt;0.3</td>
</tr>
<tr>
<td>e⁻ beam energy on Target</td>
<td></td>
<td>Gev</td>
<td>4</td>
</tr>
<tr>
<td>e⁻ bunch charge on Target</td>
<td></td>
<td>nC</td>
<td>10</td>
</tr>
</tbody>
</table>

The repetition rate is 50 Hz and one-bunch-per-pulse is considered. The linac contains electron linac and positron linac. To achieve 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 extracted to damping ring, then the positron beam are extracted 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 required 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
  \[ U₀ = 88.5 \times 10³ \frac{Eₑ⁻(GeV)}{\rho(m)} \]  \hspace{1cm} (1)
  \[ rₑ⁻ = \frac{2 Eₑ⁻ Tₑ⁻}{U₀} \]  \hspace{1cm} (2)

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

\[ \tau_s = \frac{E_e T_0}{U_0} \]  
\[ \varepsilon_s = C \gamma^2 \phi \left( \frac{3}{4} \sin^2 \left( \frac{\mu}{2} \right) + \frac{1}{60} \sin^4 \left( \frac{\mu}{2} \right) \right) \]  

\[ \delta_0 (\%) \quad 0.049 \]  
\[ \varepsilon_0 (\text{mm.mrad}) \quad 302 \]  
\[ \text{Nature } \sigma_z (\text{mm}) \quad 7 (23\text{ps}) \]  
\[ \text{Extract } \sigma_z (\text{mm}) \quad 7 (23\text{ps}) \]  
\[ \varepsilon_{\text{ext xy}} (\text{mm.mrad}) \quad 434/145 \]  
\[ \delta_{\text{inj}} / \delta_{\text{ext}} (\%) \quad 0.25 / 0.05 \]  
\[ f_{\text{RF}} (\text{MHz}) \quad 650 \]  
\[ V_{\text{RF}} (\text{MV}) \quad 1.8 \]  

**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.

**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.
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.

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.

<table>
<thead>
<tr>
<th></th>
<th>BC (case I)</th>
<th>BC (case II)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_0$ (Gev)</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>$\delta_0$ (%)</td>
<td>0.05</td>
<td>0.23</td>
</tr>
<tr>
<td>$\sigma_z0$ (mm)</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>$f_{RF}$ (MHz)</td>
<td>2856</td>
<td>14.5</td>
</tr>
<tr>
<td>$V_{RF}$ (MV)</td>
<td>19.3</td>
<td>14.5</td>
</tr>
<tr>
<td>$\phi_{RF}$ (degree)</td>
<td>87</td>
<td>86</td>
</tr>
<tr>
<td>$R_{56}$ (m)</td>
<td>-3</td>
<td>-4</td>
</tr>
<tr>
<td>$E_f$ (Gev)</td>
<td>1.101</td>
<td>1.101</td>
</tr>
<tr>
<td>$\delta_f$ (%)</td>
<td>0.23</td>
<td>0.17</td>
</tr>
<tr>
<td>$\sigma_zf$ (mm)</td>
<td>1.5 (5ps)</td>
<td>2 (6.7ps)</td>
</tr>
</tbody>
</table>

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 fulfill 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
