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OVERALL DESIGN OF THE CEPC INJECTOR LINAC*

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Abstract

The CEPC injector consists of linac and booster. To meet the requirement of the booster, the linac should provide 10 GeV electron and positron beam at a repetition frequency of 100 Hz. In this paper, the overall design of the linac has introduced. For the linac one-bunch-per-pulse is adopted and bunch charge should be larger than 3 nC in the design. A 1.1 GeV damping ring with 75.4 m circumference has adopted to reduce the transverse emittance of positron beam to suitably small value.

INTRODUCTION

Circular Electron-Positron Collider (CEPC) [1] is a 100 km ring e^+ e^- collider for a Higgs factory. It has proposed by the Institute of High Energy Physics (IHEP) of the Chinese Academy of Sciences (CAS) in collaboration with a number of institutions from various countries. The CEPC accelerator is composed of linac, booster, collider and the transports lines. The energy of the collider is 120 GeV. The CEPC booster provides 120 GeV electron and positron beams to the CEPC collider and is in the same tunnel as the collider. The energy of the linac is 10 GeV. The layout of CEPC accelerator shows in Fig. 1.

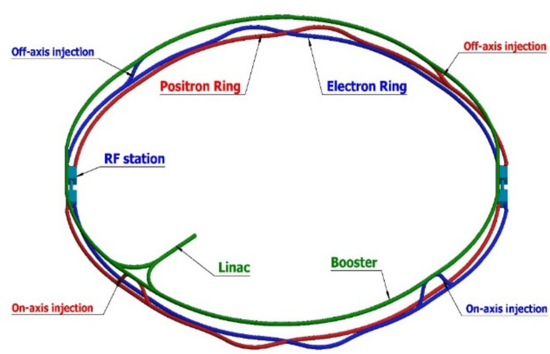

Figure 1: Layout of CEPC accelerator.

OVERVIEW OF THE LINAC

The linac is a normal conducting S-band linac with frequency in 2860 MHz and provide electron and positron beams at an energy up to 10 GeV. The main requirements of the booster to Linac shows in Table 1. Single bunch mode has adopted and the repetition frequency is 100 Hz.

Simplicity and high availability are the design principles. The layout baseline design is the linear scheme and there are 15% backups of the klystrons and accelerating structures. Considering the potential to meet higher requirements and the ability to update in the future, the bunch charge is designed to larger than 3 nC, which is important for positron source design.

Table 1: The requirements of the Booster to the Linac

Parameters	**Value**	**Unit**
e^- /e^+ beam energy	10	GeV
Repetition rate	100	Hz
e^- /e^+ bunch population	>1.5	nC
Energy spread (e^- /e^+)	$<2\times10^{-3}$	-
Emittance (e^- /e^+)	<120	nm

The linear scheme of linac layout as the baseline design shows in Fig. 2. The linac is composed of electron source and bunching system (ESBS), the first accelerating section (FAS) where electron beam is accelerated to 4 GeV, positron source and pre-accelerating section (PSPAS) where positron beam is accelerated to larger than 200 MeV, the second accelerating section (SAS) where positron beam is accelerated to 4 GeV and the third accelerating section (TAS) where electron and positron beam are accelerated to 10 GeV. Electron bypass transport line (EBTL) scheme has considered for bypass electron beam in electron mode. A 1.1 GeV damping ring at SAS is introduced to reduce the positron beam emittance. The short-range wakefields have considered in the simulation of beam dynamics.

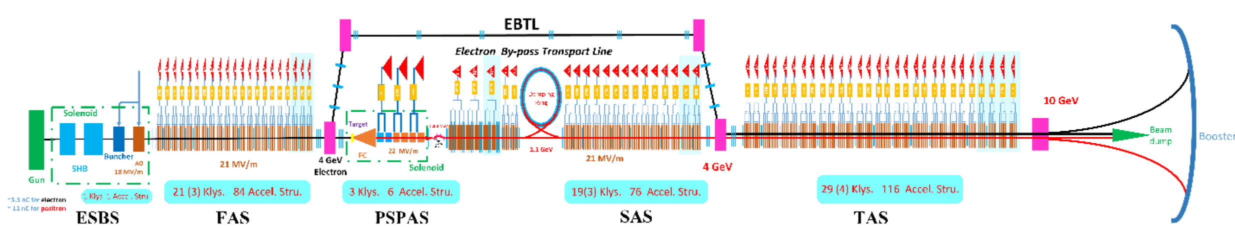

Figure 2: Layout of CEPC Linac.

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ELECTRON LINAC

ESBS

The ESBS contains the electron source and a bunching system. Two operation modes of the electron source are required; one is to provide a 3.3 nC bunch charge for electron injection and the other is to provide a 11 nC bunch charge as the primary electron beam for positron production. The bunching system consists of two sub-harmonic bunching cavities with frequency in 143 MHz and 572 MHz, an S-band buncher and an S-band accelerating structure with frequency in 2860 MHz. The transverse focussing element in the bunching system is solenoid. Beam distribution at exit of the ESBS and normalized rms emittance along the beam direction is shown in Fig. 3. The normalized rms emittance at the ESPS exit is 80 mm-mrad and the transmission efficiency is about 90%.

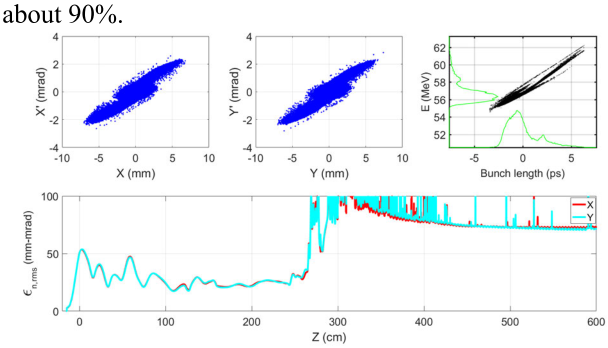

Figure 3: Beam distribution at the exit of ESBS (top) and normalized rms emittance (below) along the beam direction.

Electron Linac Mode

The electron Linac is composed of FAS, EBTL and TAS. The horizontal distance between EBTL and the Linac is 2 m. The EBTL adopt local achromatic design and dispersion function is controlled within 0.5 m. The optical functions are shown in Fig. 4. The start-to-end dynamics simulation results of electron Linac with the bypass section are shown in Fig. 5, where the rms energy spread is 0.11% and the rms emittance is about 5 nm at the Linac exit. All the results can meet the requirements of the booster.

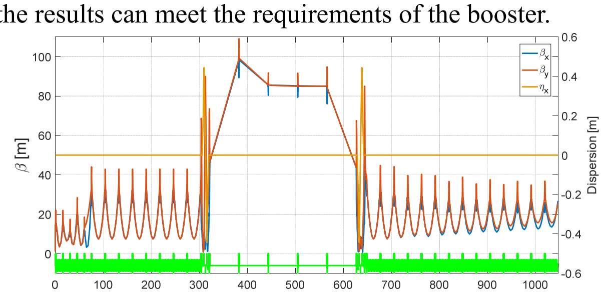

Figure 4: Optical functions of the electron linac.

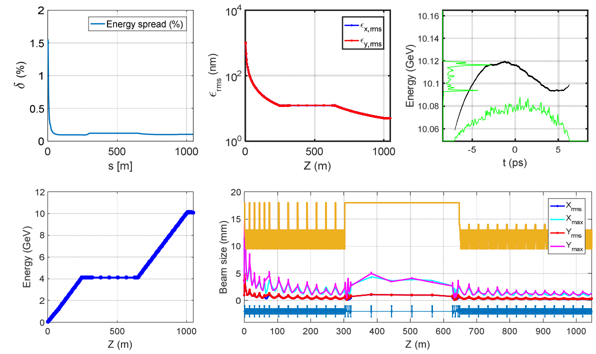

Figure 5: Beam dynamic simulation results for the electron linac, including energy spread (top-left), emittance (top-middle), longitudinal beam distribution (top-right), energy (bottom-left) and beam size (bottom-right).

POSITRON LINAC

PSPAS

A schematic of the positron source and pre-accelerating section (PSPAS) is shown in Fig. 6, including the target, flux concentrator (FC) which is an adiabatic matching device (AMD), caputre accelerating structures (blue), pre-acclerating structures (orange) and a chicane system. All the accelerating structures are same and each klystron drive two accelerating structures. The chicane systme is designed to dump the electron beam and photons. To achieve larger than 3 nC bunch charge positron beam at linac exit, a 4 GeV primary electron beam with an intensity of 10 nC/bunch is required. The length of the tungsten target is 15 mm and the RMS beam size of electron beam is 0.5 mm. The average electron beam power is 4 kW.

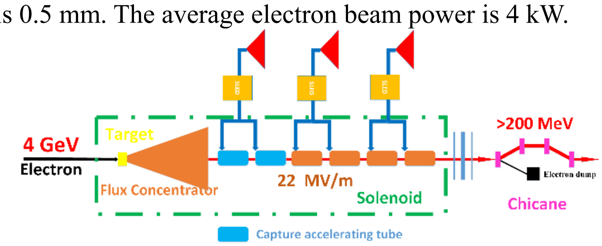

Figure 6: The layout of CEPC positron source.

The magnetic field of AMD is a pseudo-adiabatically changing solenoid field from peak 6 T to 0.5 T, which is a flux concentrator superimposed on a 0.5-T DC solenoid field. Comprehensive consideration of positron capture efficiency, emittance control and accelerating structure design, the aperture of accelerating structure has chosen as 25 mm. Figure 7 shows the positron yield at the second capture accelerating structure exit with different accelerating gradient and input phase corresponding to RF phase. There are two phase range where have higher positron yield: deceleration mode and acceleration mode. According to positron yield and consideration on beam energy, the accelerating gradient has chosen as 22 MV/m.

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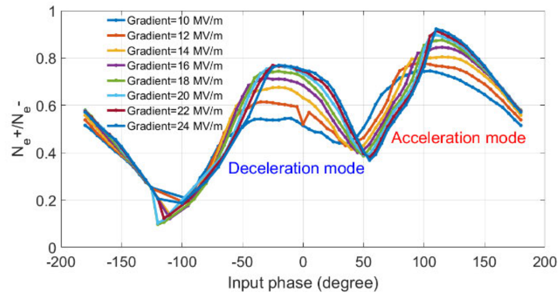

Figure 7: Positron yield at the second accelerating structure exit with different accelerating gradient and phase.

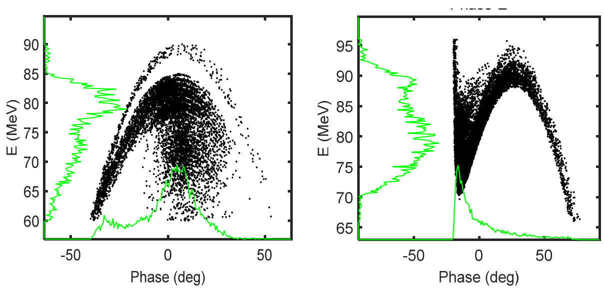

Figure 8: Beam distribution at the second accelerating structure exit, left is deceleration mod and right is acceleration mod.

The longitudinal beam distributions of deceleration mode and acceleration mode at the capture accelerating structure exit show in Fig. 8. From the simulation results acceleration mode have more compact phase spectrum, so the acceleration mode has adopted in the simulation. The deceleration mode is also possible in the operation of linac, same as KEKB [2]. The envelope from target exit to pre-accelerating section exit shows in Fig. 9. The distribution at pre-accelerating section exit shows in Fig. 10, where the energy cut off range is from 235 MeV to 265 MeV and the phase cut off range is from -8° to 12°. In this cut off condition the positron beam yield (Ne^+/Ne^-) is about 0.55, which can meet the bunch charge requirement.

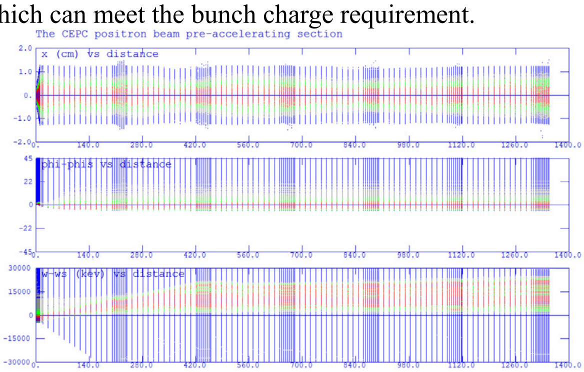

Figure 9: Beam envelope from target exit to pre-accelerating section exit.

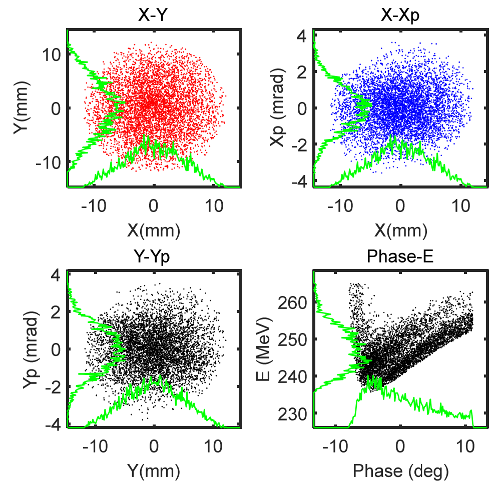

Figure 10: The distribution at pre-accelerating section exit.

Damping Ring

The energy of DR is 1.1 GeV and the circumference is 75.4 m [3]. The DR has a racetrack shape and the arcs have designed with 60 degrees FODO cell. Figure 11 shows the twiss parameters of the DR and the main parameters show in Table 2.

The injected emittance (normalized) for DR is 2500 mm·mrad and the injected energy spread is smaller than 0.2%. The positron beam will be stored in DR for 20 ms according to the 100 Hz repetition rate and two-bunch storage scheme. The extracted emittance is better to be smaller than one quarter of the injected emittance. Considering the issue of injection efficiency, the transverse acceptance of DR should be larger than five times of the injection beam size.

Before damping ring, the energy spread of the positron bunch should be reduced in order to match the RF acceptance of damping ring. After damping ring, longitudinal bunch length control must be provided to minimize energy spread 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.

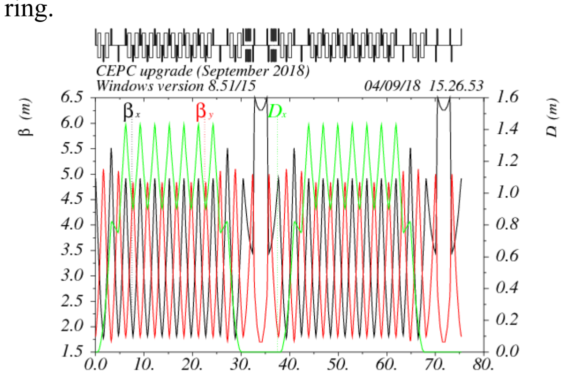

Figure 11: Twiss parameter for the whole ring.

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Table 2: Main Parameters of Damping Ring

Parameters	Value	unit
Energy	1.1	GeV
Circumference	75.4	m
Bending radius	3.6	m
Dipole strength B_0	1.03	T
U_0	36.3	keV/turn
Damping time x/y/z	15.2/15.2/7.6	mS
δ_0	0.05	%
ε_0	376.7	mm.mrad
injection σ_z	5	mm
Extract σ_z	7.5	mm
ε_{inj}	2500	mm.mrad
$\varepsilon_{ext\ x/y}$	530/180	mm.mrad
δ_{inj} /δ_{ext}	0.18 /0.05	%
Energy acceptance by RF	1.0	%
f_{RF}	650	MHz
V_{RF}	2.0	MV

Positron Linac Mode

The positron Linac is composed of SAS and TAS. Simulations are performed over an energy range from 200 MeV to 10 GeV. The third accelerating section accelerates both prositron and electron beams from 4 GeV to 10 GeV. Because the emittance of the positron beam is larger than the electron beam, the lattice of the TAS is based on the positron beam requirements. In the low-energy part of the SAS, the focusing structure is FODO and the quadrupoles nest on the accelerating structure. As the emittance decreases with energy increase and the damping ring the focusing structures are varied to decrease the number of quadrupole: one-triplet-one-accelerating-structure, one-triplet-four-accelerating-structures and one-triplet-eight-accelerating-structures. Four focusing structures shows schematically in Fig. 12.

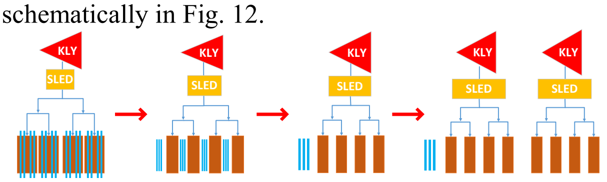

Figure 12: The focusing structures of positron linac.

Beam simulation results are shown in Fig. 13. At linac exit the energy spread is 0.16% and the rms emittance is 30/10 nm with the damping ring, which all meet the requirements of booster. The break in the plots is at the position of the DR.

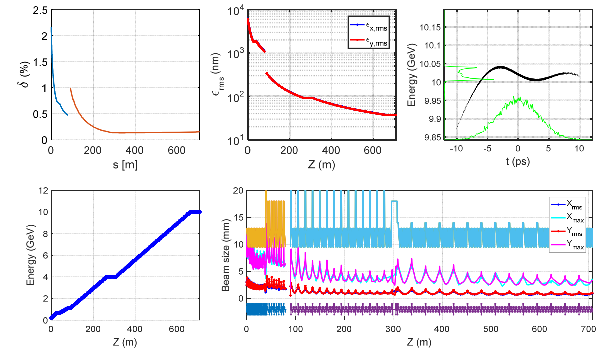

Figure 13: Beam dynamic simulation results for the positron linac, including energy spread (top-left), emittance (top-middle), longitudinal beam distribution (top-right), energy (bottom-left) and beam size (bottom-right).

CONCLUSION

The linac provides 10 GeV electron and positron beam with single bunch mode to the booster. A bypass section has been designed for the e- to make the e+ target simple. A fixed tungsten target has used in the positron source system. The e- beam on the target is 4 GeV & 10 nC. A damping ring is in the position of 1.1 GeV to reduce the positron emittance. The lianc design is meet the requirments of the booster.

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