CEPC LINAC DESIGN AND BEAM DYNAMICS*

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Abstract

Circular Electron-Positron Collider (CEPC) is a 100 km ring e^+e^- collider for a Higgs factory, which is organized and led 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 linac of CEPC is a normal conducting S-band linac with frequency in 2856.75 MHz and provide electron and positron beam at an energy up to 10 GeV with bunch charge in 1.0 nC and repetition frequency in 100 Hz. The linac scheme will be detailed discussed in this paper, including electron bunching system, positron source design, and main linac. Positrons are generated using a 4 GeV electron beam with bunch charge 10 nC hit tungsten target and the positron source design are presented. The beam dynamic results with longitudinal short Wakefield, transverse Wakefield and errors are presented.

INTRODUCTION

With the discovery of the Higgs particle at the Large Hadron Collider at CERN in July 2012, further research and measurement in Higgs is very important for particle physics. Because of the energy of Higgs is much lower than expected before, it is big possibility to build a circular collider as a Higgs factory. In September 2012, Chinese scientists proposed a Circular Electron Positron Collider (CEPC) in China at 240 GeV centre of mass for Higgs studies [1]. It could later be used to host a Super Proton Proton Collider (SppC) in the future as a machine for new physics and discovery. After that a great effort have been made in parameter choice and physics design [2][3].

With the deep study and more consideration in CEPC the design scheme has several versions compare to the Pre-CDR [4]. The latest scheme has some updates: the circumference is 100 km, baseline design of main ring is double ring, the linac energy is 10 GeV and also some more detailed optimizations.

Table 1: Main Parameters of CEPC Linac

Parameter	Unit	Value
e^-/e^+ beam energy	GeV	10
Repetition rate	Hz	100
e^-/e^+ bunch population	nC	1.0
Energy spread (e^-/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 injector is composed of linac and booster. The Booster provides 120 GeV electron and positron beams to the CEPC collider and is in the same tunnel as the collider. The first part of the injector is a normal conducting S-band linac with frequency in 2856.75 MHz and provide electron and positron beam at an energy up to 10 GeV. The main parameters are shown in Table 1. The repetition rate is increased to 100 Hz from 50 Hz at Pre-CDR and one-bunch-per-pulse is considered, the linac mode maybe will be changed according to the injection scheme study. With the study of CEPC main ring and injection scheme, the bunch charge is decreased to 1.0 nC from 3.2 nC at Pre-CDR, however we also keep the ability to provide a 3.2 nC bunch beam by now. To obtain a 3.2 nC positron beam, one need a 4 GeV primary electron beam with bunch charge in 10 nC hit a tungsten target.

Based on a lot of discussion of linac scheme, we choose the linear scheme as the baseline design by now, which is

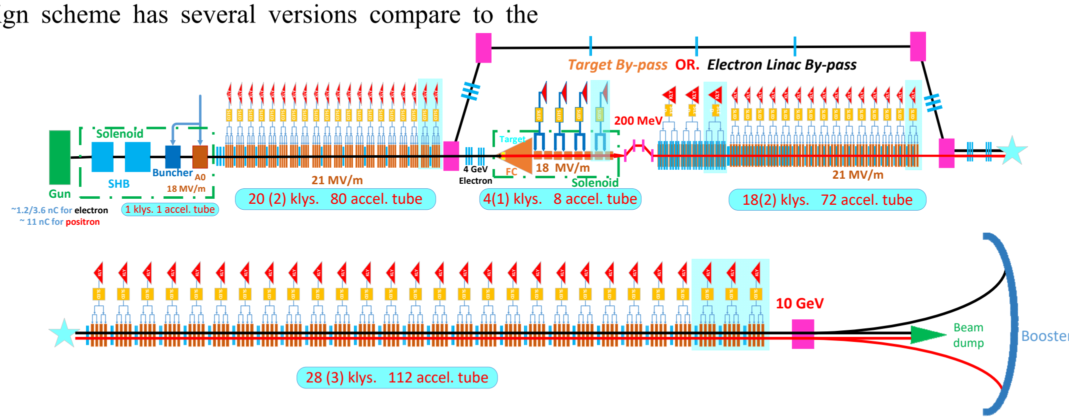

Figure 1: CEPC linac layout.

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shown in Fig. 1 and 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 200 MeV, and the second accelerating section (SAS) where electron and positron beam are accelerated to 10 GeV. The electron bypass method, electron transport line bypass and target bypass, have not yet been determined. The detailed discussion will be presented as following.

SUB-SECTION OF CEPC LINAC

ESBS

According to positron source design, two operation modes of electron source are required. One is to provide a 1.2 nC (or 3.6nC) bunch charge for electron injection, and another is to provide an 11 nC bunch charge as the primary electron beam for positron production, where one assumes the transmission efficiency of bunching system is 90%. The bunching system is consisting of two sub-harmonic bunching cavities operating at 142.8375 MHz and 571.35 MHz, an S-band buncher at 2856.75 MHz and a normal S-band accelerating tube at 2856.75 MHz. For the high current mode, in the simulation results the normalized rms emittance is about 80 mm-mrad and transmission efficiency is 91% at exit of ESBS, which is shown in Fig. 2, and more optimization in beam dynamics will be continued.

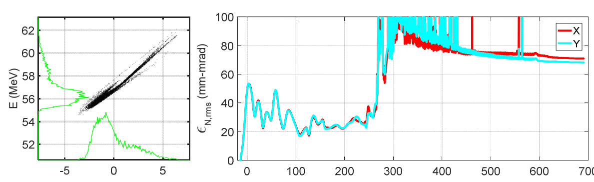

Figure 2: Beam distribution at exit of ESBS (left) and normalized rms emittance (right) along beam direction.

FAS

The first accelerating section is accelerating electron beam from 50 MeV to 4 GeV by 18 klystrons and 72 S-band accelerating tubes with the gradient 21 MV/m. In this section one klystron with SLED drive 4 accelerating tubes. In one period there are 4 accelerating tubes and one triplet in the first five periods and 8 accelerating tubes and one triplet in the following periods, which is shown in Fig. 3.

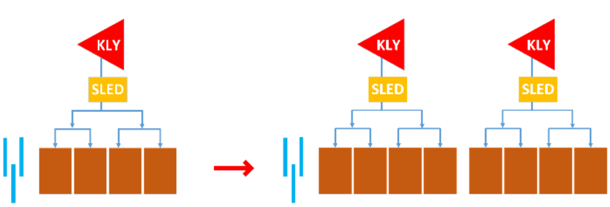

Figure 3: Period structure of FAS.

The considered bunch charge is 10 nC in the simulation, and the short longitudinal Wakefield and transverse Wakefield are considered, which is Yokoya's Wakefield model for periodic linac structure [5] and shown in Fig. 4. The beam distribution at exit of FAS is shown in Fig. 5, and the energy spread is large but can meet requirements for positron production.

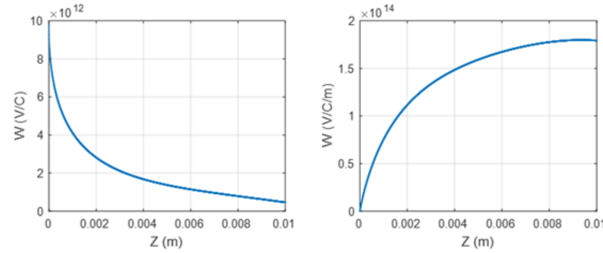

Figure 4: The short-range Wakefield of S-band accelerating tube, left is longitudinal Wakefield and right is transverse Wakefield.

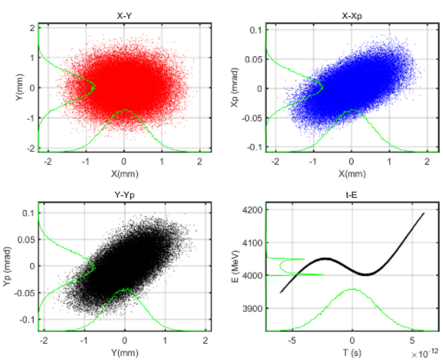

Figure 5: Beam distribution at exit of FAS.

PSPAS

A schematic of the positron source and pre-accelerating section (PSPAS) is shown in Fig. 1. A high energy electron beam strikes the tungsten target and a wide spectrum of low energy electrons, positrons, and photons are produced. Considering the positron yield shown in Fig. 6 and energy deposition, we choose the target length as 15 mm.

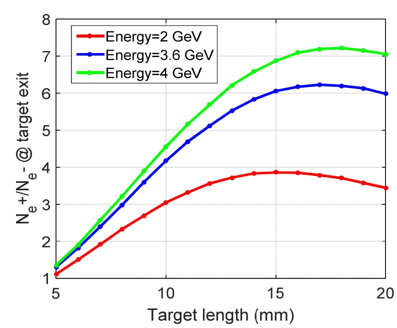

Figure 6: Positron yield with different target length and different electron energy.

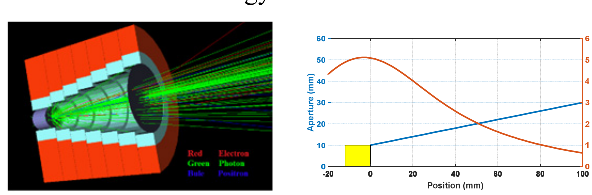

Figure 7: Schematic (left) , the magnetic field and aperture (right) of AMD. The yellow block is target.

The large transverse emittance of the positron beam emerging from the target is transformed to match the pre-accelerating section with AMD, which is shown in Fig. 7.

Immediately following the AMD there are six 2 m length high-gradient constant-impedance S-band (2856.75 MHz) accelerating tube with constant aperture 15 mm. In the pre-accelerating section, one klystron source supply two accelerating tube with gradient in 18 MV/m and the positrons are accelerated to 200 MeV. The pre-accelerating section uses a uniform solenoid for focusing, which magnetic field is 0.5 T. The normalized rms emittance is 3000 mm-mrad.

SAS

Because the emittance of positron beam is much larger than electron beam, we design the lattice of SAS based on positron beam. In the low energy part, the focusing structure is FODO and the quadrupoles are nesting on accelerating tube. With the energy goes up we change focusing structure to decrease quadrupole number to save cost, which is one triplet one accelerating tube, one triplet two accelerating tubes and one triplet four accelerating tubes, and the four focusing structures are shown in Fig. 8.

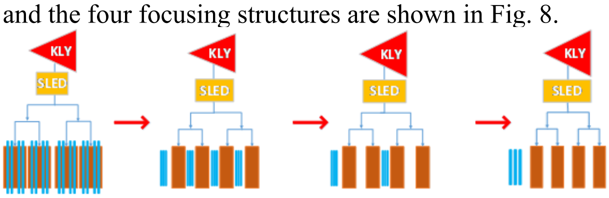

Figure 8: The focusing structures of SAS.

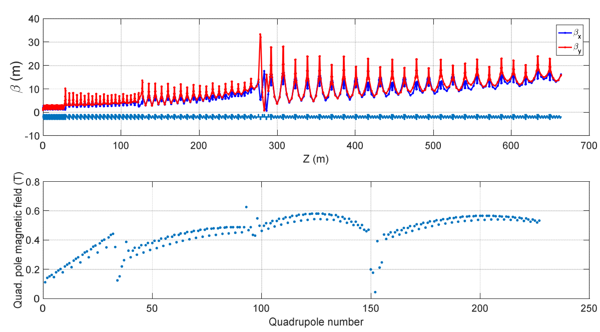

Figure 9: The β function and quadrupole pole magnetic field along the linac.

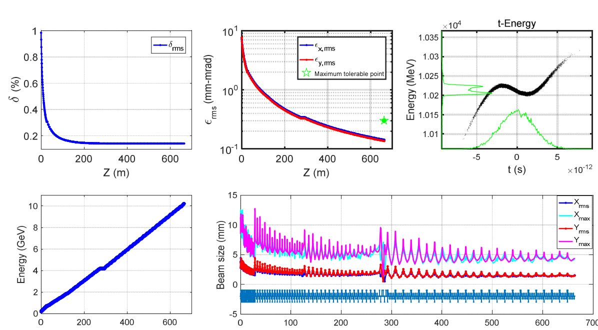

Figure 10: The simulation results along the linac: energy spread (top left), emittance (top middle), longitudinal phase space distribution (top right), energy (down left) and beam sizes (down right).

For the beam dynamics we want smaller β function to keep smaller beam size, which means strong focusing, but also should keep the maximum magnetic field on the pole of quadrupole smaller than 0.6 T, so we need balance these factors. The β function and quadrupole pole magnetic field along the linac is shown in Fig. 9.

Considering the short Wakefield, one can get the beam simulation results with bunch charge 3.2 nC including energy spread, emittance, longitudinal phase space distribution, energy and beam sizes, which is shown in Fig.10 and can meet the requirements.

Because the beam orbit jitter caused by quadrupole vibration cannot be corrected, we should control the beam orbit jitter carefully based on the injection study. Figure 11 shows the vertical rms beam orbit jitter with different quadrupole vibration amplitude. If the orbit jitter should smaller than 0.1 mm, quadrupole vibration amplitude need be controlled within 2 μm.

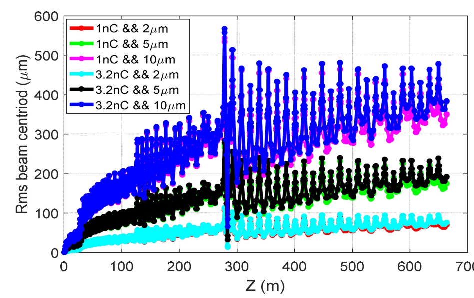

Figure 11: The vertical rms beam orbit jitter with different quadrupole vibration amplitude along the linac.

CONCLUSION

The linac of CEPC is a normal conducting S-band linac with frequency in 2856.75 MHz and provide electron and positron beam at an energy up to 10 GeV. The linac scheme is detailed discussed in this paper, including ESBS, FAS, PSPAS and SAS. The detailed simulation results are presented and can meet the requirements. There is no issue that defies solution for CEPC linac and more optimizations should be continued.

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