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ALTERNATIVE DESIGN OF CEPC LINAC*

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Abstract

Circular Electron-Positron Collider (CEPC) is a 100 km ring e+ e- collider for a Higgs factory. The injector is composed of a Linac and a Booster. The baseline design of CEPC Linac is a normal conducting S-band linear accelerator with frequency in 2860 MHz, which can provide electron and positron beam at an energy up to 10 GeV and bunch charge up to 3 nC. To reduce the design difficulty of booster and booster magnet, an alternative design of the Linac with C-band accelerating structure at high energy part is proposed and the energy is up to 20 GeV. In this paper, the physics design of this scheme is presented.

INTRODUCTION

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 physics design [2].

The injector of CEPC is composed of a Linac and a full energy booster. The first part of the injector 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 [3, 4]. The main parameters of the CEPC linac are shown in Table 1 and layout is shown in Fig.1. 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 produced and accelerated to more than 200 MeV, the second accelerating section (SAS) where positron beam is accelerated to 4 GeV, the third accelerating section (TAS) where electron beam and positron beam are accelerated to 10 GeV, the electron bypass transport line (EBTL) where the electron beam is bypass the PSPAS and SAS section and one damping ring (DR) to reduce the emittance of positron beam. The electron Linac consists of ESBS, FAS, EBTL and TAS. The positron Linac consists of ESBS, FAS, PSPAS, SAS, DR and TAS. The horizontal distance between EBTL and SAS is 2.0 m. The Linac should be have potential to meet higher requirements and upgrade in the future, the designed bunch charge is larger than 3 nC both for electron and positron beam. Based on this consideration, the energy of electron beam for positron production is chosen as 4 GeV and the positron yield of positron source with some cut-off condition is 0.55 [5].

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	>1.5
Energy spread (e^-/e^+)		$<2\times10^{-3}$
Emittance (e^-/e^+)	nm	<120

The CEPC booster [6] provides 120 GeV electron and positron beams to the CEPC collider and is in the same tunnel as the collider, which of circumference is 100 km. The electron beam is ramped from 10 GeV to 120 GeV in the booster. The magnetic field of dipole magnet is about 30 Gs at injection energy. It's very challenging for magnet design and operation, on the other hand, the operating mode of magnet power supply is ramping and dynamic, so it's a very critical issue. In order to reduce the design difficulty, increasing the energy of the Linac is a good way.

Based on this idea, an alternative 20-GeV Linac scheme is proposed. High gradient accelerating structure is needed for high energy linac to reduce the length and cost. Considering the bunch charge is not very high and the emittance is small, the C-band accelerating structure is introduced to the alternative design. The C-band accelerating structure is used to replace S-band accelerating structure in the TAS and the energy of the Linac is increased to 20 GeV. The alternative design is presented and discussed in this paper.

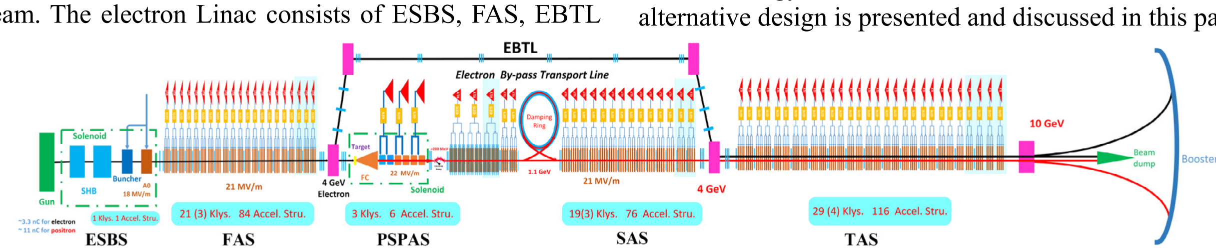

Figure 1: The layout of the CEPC Linac.

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PHYSICS DESIGN

In order to increase the Linac energy and minimize the increasing in the length and cost of the Linac, the C-band accelerating structure is used to replace the S-band accelerating structure in the whole TAS, which means the C-band accelerating structure is used from 4 GeV to 20 GeV. The designed bunch charge is 3 nC and one should be pay attention to the Wakefield in C-band accelerating structure. The Linac adopts one-bunch-per-pulse mode, so one just consider the short-range Wakefield which can be obtained by analytical method. The basic shape of a periodic structure is shown in Fig.2, where L is the cell length, a is the iris half aperture, b is cavity radius, t is iris width and g is the cavity length. The longitudinal and transverse short-range Wakefield for small s is obtained by the following formula [7, 8]:

$$W_L(s) = \frac{Z_0 c}{\pi a^2} e^{-\sqrt{\frac{s}{S_1}}}, \tag{1}$$

$$S_1 = \frac{g}{8}\left(\frac{a}{\left(1-0.465\sqrt{\frac{g}{L}}-0.07\frac{g}{L}\right)L}\right)^2, \tag{2}$$

$$W_T(s) = \frac{4Z_0 c S_2}{\pi a^4}\left[1-\left(1+\sqrt{\frac{s}{S_2}}\right)e^{-\sqrt{\frac{s}{S_2}}}\right], \tag{3}$$

$$S_2 = 0.169\frac{a^{1.79} g^{0.38}}{L^{1.17}}. \tag{4}$$

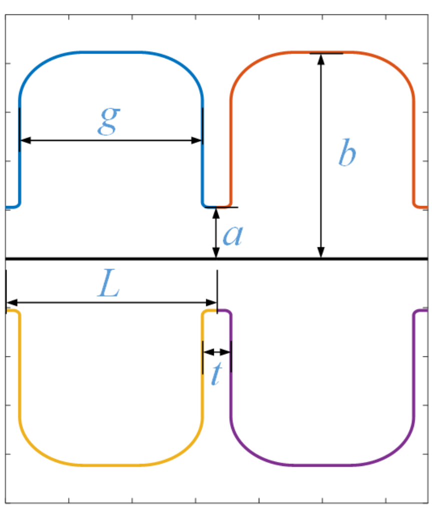

Figure 2: Basic shape of a periodic structure.

The main parameters of accelerating structure are shown in Table 2 and the short-range Wakefields are shown in Fig.3, which are obtained based on Eq. (1) and Eq. (3). From the results, one can get that the C-band accelerating structure have larger Wakefield. To meet the energy spread requirement, shorter bunch length is needed for C-band accelerating structure, so the bunch compressor system in the transport line from the damping ring (DR) to the Linac (DTL) needs to be carefully designed and optimized. According to the requirement of energy spread that is 0.2%, the rms bunch length should be controlled within 0.5 mm. Based on the preliminary design of the damping ring [9], the normalized emittance after DTL is about 600 mm-mrad and 200 mm-mrad in horizontal plane and vertical plane.

For the transverse focusing, there are two period structures: one triplet 4 accelerating structure and one triplet 8 accelerating structure. With the energy increasing, the focusing strength K decreases slowly to reduce the requirements of quadrupole gradient. The optics function of the TAS is shown in Fig.4. The total length of the 20-GeV Linac has increased by about 200 m. Considering the emittance after DR is small, one scheme with fewer quadrupoles is also proposed and studying.

Table 2: Main Parameters of S-band and C-band Accelerating Structure

Parameter	Unit	S-band	C-band
Frequency	MHz	2860	5720
Length	m	3.1	1.8
Mode		2π/3	4π/5
Iris aperture	mm	20~24	11.8~16
Iris width	mm	4.5	4.0
Gradient	MV/m	21	45

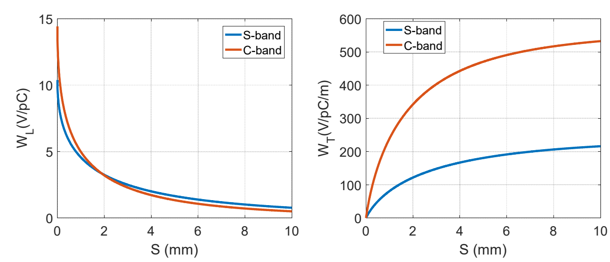

Figure 3: The short-range Wakefield of S-band and C-band accelerating structure.

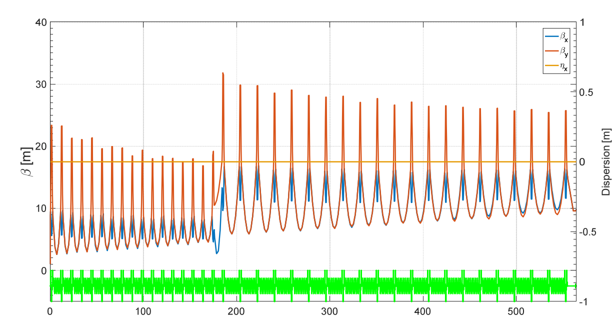

Figure 4: Optics function of the TAS.

DYNAMIC RESULTS

Based on the above design, multi-particle tracking has been finished by Elegant [10]. Using the injection point from the DR to the Linac as the starting point in the simulation of positron beam, where beam energy is from 1.1 GeV to 20 GeV. The bunch charge is 3.2 nC in the simulation.

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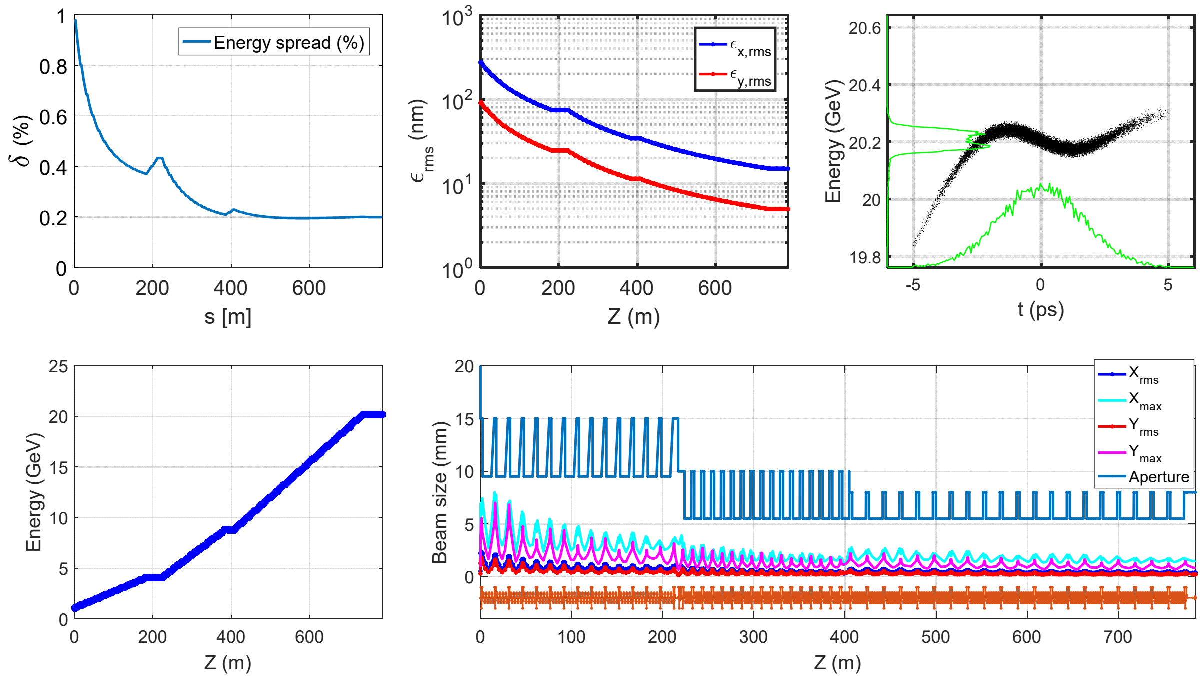

Figure 5: Beam dynamic simulation results of positron Linac: rms energy spread (top left), rms emittance (top middle), longitudinal phase space distribution (top right), energy (down left) and beam sizes (down right).

Considering the bunch compressor system design and energy spread requirements at the Linac exit, bunch length adopts 0.5 mm and energy spread adopts 1.0% at the starting point with 3σ truncated Gaussian distribution. The simulation results are shown in Fig.5, which including the energy spread, emittance, beam distribution, energy and beam sizes. From the simulation, the energy spread is 0.2% at the Linac exit, the emittance is 15 nm and 5 nm in horizontal plane and vertical plane and the energy is 20 GeV, which can meet the requirements. Further optimization and error study are still going on.

CONCLUSION

The baseline design of the CEPC Linac is a 10-GeV S-band normal conducting linear accelerator. To reduce the difficulty of magnet design in the booster, a 20-GeV alternative design with S-band and C-band accelerating structure is proposed. In this paper detailed design of this scheme is presented and the simulation results show that the design can meet the requirements.

ACKNOWLEDGMENT

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