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CEPC LINAC DESIGN AND ERROR STUDY*

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Abstract

Circular Electron-Positron Collider (CEPC) is a 100 km ring e^+e^- collider for a Higgs factory, including the double ring for collider and the injector. The injector is composed of the linac and booster. 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. The beam dynamic results with short-range Wakefields and detailed error study including misalignment errors and field errors also be presented.

INTRODUCTION

With the discovery of the Higgs particle at the Large Hadron Collider at CERN in July 2012, further re-search and measurement in Higgs is very important for particle physics. 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 scheme has several versions compared with the pre-CDR [4]. The latest scheme has some updates, the baseline design of main ring is double ring with circumference 100 km and the linac energy is 10 GeV and also some more detailed optimizations.

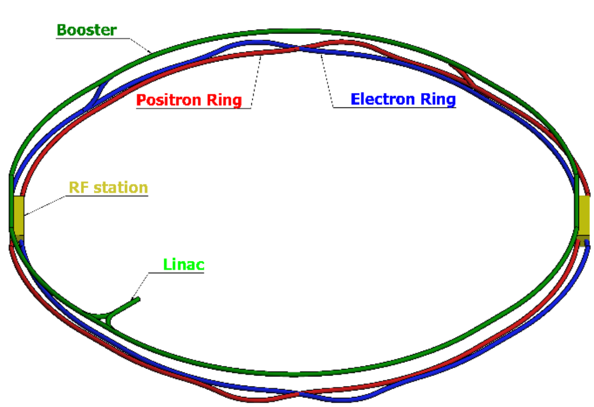

Figure 1: Layout of CEPC.

CEPC is composed of double ring for collider and the injector including linac and booster. The Booster provides 120 GeV electron and positron beams to the CEPC collider and is installed above the collider in the same tunnel, which is shown in Fig.1. Considering the very low magnetic field at the injection of booster, one pre-booster with energy in 45 GeV given consideration to Z study have been proposed.

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. With the study of CEPC booster and injection scheme, one-bunch-per-pulse mode is considered and 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. In the baseline design a 4 GeV primary electron beam with bunch charge in 10 nC hit a tungsten target to obtain a 3.2 nC positron beam.

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

Based on a lot of discussions of linac scheme, we choose the linear scheme as the baseline design, which is shown in Fig.2 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 or target bypass, have not yet been determined. The beam dynamics will be presented. The errors study has been considered carefully, including the misalignment errors of magnets and accelerating tubes, correction scheme, filed errors and accelerating gradient errors of accelerating tube.

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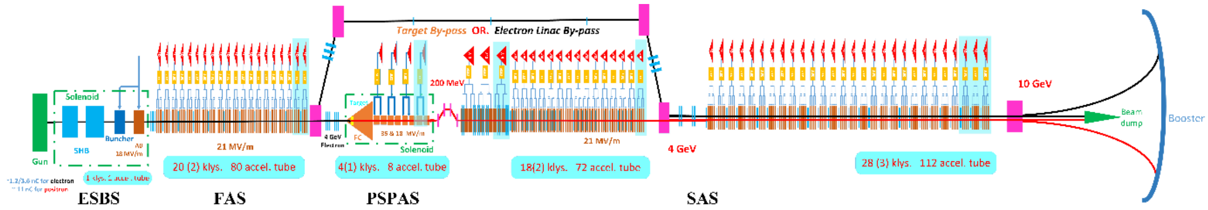

Figure 2: CEPC linac layout.

BEAM DYNAMICS OF LINAC

The linac is composed of ESBS, FAS, PSPAS and SAS , which provide electron and positron beam with the energy in 10 GeV. The detailed design and beam dynamics results can been proposed [5].

There are different transverse focusing structures in different sections. The solenoid focusing structure is adopted in ESBS and PSPAS section to obtain large beam transmission. For the FAS section there are 2 period structures shown in Fig.3: one triplet group 4 accelerating tubes and one triplet group 8 accelerating tubes. Because the emittance of positron beam is much larger. There are four period structures changing with energy increasing in SAS section shown in Fig.4: FODO structure where the quadrupoles are nesting on accelerating tube, one triplet group one accelerating tube, one triplet group two accelerating tubes and one triplet group four accelerating tubes.

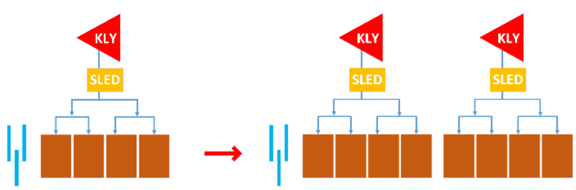

Figure 3: Period structure of FAS.

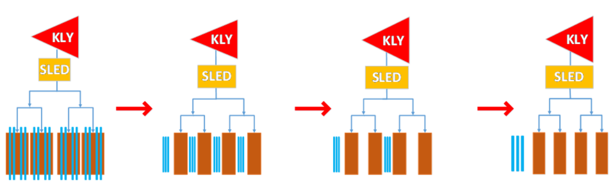

Figure 4: The focusing structures of SAS.

To shorten linac length and improve power efficiency, the SLAC energy doubler (SLED) and one klystron drive 4 accelerating tubes mode have been adopted. Beam is accelerated by S-band accelerating tube with frequency in 2856.75 MHz and accelerating gradient in 21 MV/m. To get higher positron yield constant impedance S-band accelerating tubes with radius in 15 mm and accelerating gradient in 35 MV/m are used in PAPAS. Considering one-bunch-per-pulse mode and high bunch charge for positron generation, the short-range longitudinal Wakefield and transverse Wakefield are included in beam dynamics simulation, using Yokoya's Wakefield model for periodic linac structure [6].

Because the positron beam has larger emittance, we focused on the beam dynamics of positron beam. Considering the short-range Wakefield, one can get beam simulation results with bunch charge 3.2 nC including energy spread, emittance, longitudinal phase space distribution, energy and beam sizes, which are shown in Fig.5 and can meet the requirements.

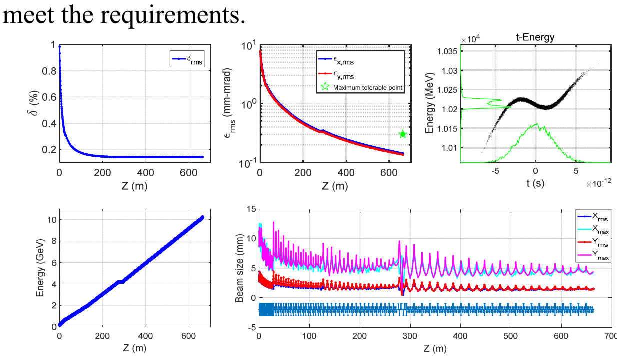

Figure 5： The simulation results along the linac: energy spread (top left), emittance (top middle), longitudinal phase space distribution (top right), energy (down left) and beam sizes (down right).

ERROR STUDY

All the devices having electromagnetic field influence over the beam have installation errors including translational errors and rotational errors, and also field errors. We can classify the possible error sources into three groups:

1. Misalignment errors: affecting all the elements with translational errors and rotational errors, e.g. solenoids, quadrupoles, accelerating cavities, etc.
2. Field errors: affecting the fields as well as the phases of accelerating tubes and the fields of magnets.
3. BPM uncertainty errors: affecting the orbit correction effect.

All the errors mentioned above can be also classified in two different types according to their variation properties with time: static errors and dynamic errors.

Vibration of Magnet

Because the beam orbit jitter caused by quadrupole vibration caused by ground vibration cannot be corrected, we should control the beam orbit jitter carefully to meet the requirement of booster injection. Figure 6 shows the rms beam orbit jitter with different quadrupole vibration amplitude. If the rms orbit jitter should smaller than 0.2 mm which means the maximum orbit jitter is about 0.6 mm,

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quadrupole vibration amplitude need be controlled within 5 µm.

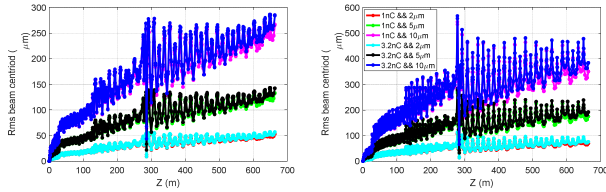

Figure 6: The rms beam orbit jitter with different quadrupole vibration amplitude along the linac.

Misalignment Errors and Correction

Following the engineering experience, the errors used for error study are shown in Table 2, which in the values of errors are RMS value with 3σ truncated Gaussian distribution. The RMS beam orbit with errors are shown in Fig.7. From the simulation results one can get the beam orbits with errors are too large and correction is necessary. One-to-one correction method is used and each period have one pair of correctors and one BPM in the correction scheme. The simulation results with correction are shown in Fig.7 and the rms beam orbit is smaller than 0.3 mm. If the requirement of beam orbit is loose, we can reduce the number of BPM and corrector. According to the simulation results, it is predictable that the number of BPM and corrector can be reduced by half.

Table 2: Errors Settings for Error Study

Error description	Unit	Value
Translational error	mm	0.1
Rotation error	mrad	2
Magnetic element field error	%	0.1
BPM uncertainty	mm	0.1

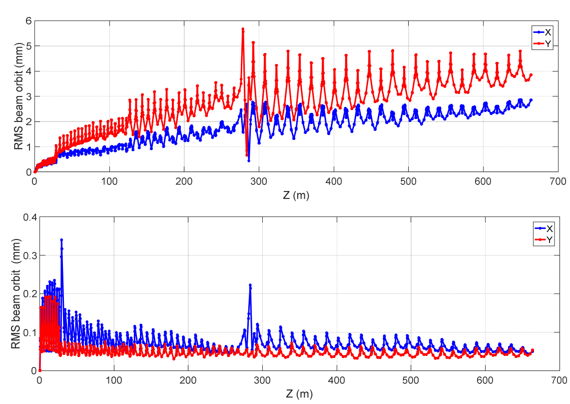

Figure 7: The RMS beam orbit with errors without correction (up) and with correction (down).

Phase Errors and Accelerating Gradient Errors

The phase errors and accelerating gradient errors of accelerating tubes can cause energy jitter. Considering the requirement of booster in energy spread is 0.2% and the energy spread without errors is about 0.15%, the energy jitter should smaller than 0.1%. Figure 8 shows the energy jitter with different phase errors and accelerating gradient errors. According to the simulation results, one can get the phase errors should be controlled in 0.5 degree and accelerating gradient errors should be controlled in 0.5%.

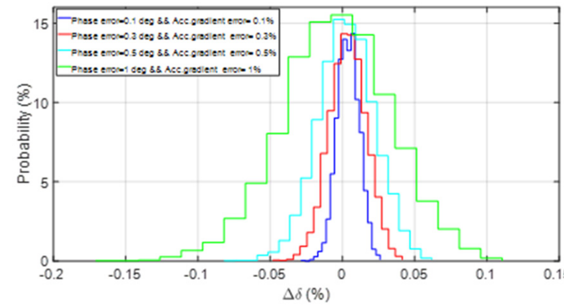

Figure 8: Energy jitter with different phase errors and accelerating gradient errors.

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 detailed simulation results and error study are presented and the linac design can meet the requirements of CEPC. There is no issue that defies solution for CEPC linac and more optimizations should be continued.

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