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PROBLEMS AND CONSIDERATIONS ABOUT THE INJECTION PHILOSOPHY AND TIMING STRUCTURE FOR CEPC

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Abstract

In this paper we will show the injection philosophy and the design of timing and filling scheme for high luminosity CEPC scheme under different energy modes. It is found that the RF frequency choice in CDR cannot meet the injection requirements for the bunch number at Z pole. A modified scheme was proposed to support the design luminosity, which basically meets our current design requirements and retains more flexibility for future high luminosity upgrade.

INTRODUCTION

The Circular Electron and Positron Collider (CEPC) is a 100 km double ring collider with two interaction points proposed to be working at four energy schemes of Z pole (45.5 GeV), W (80 GeV), Higgs (120 GeV) and tt (180 GeV) [1]. The purpose of injection and extraction timing is to connect various subsystems of the accelerator in series and work together. The difficulty of CEPC injection system is to be compatible with four energy modes at the same time, and the time structure and bunch number of these four energy modes vary greatly, and both top up and full injection should be considered simultaneously [2]. The luminosity of TDR has significantly improved compared to CDR, placing higher demands on the injection and extraction system. Z-mode is the most challenging operation in terms of charge flux delivered by the injectors. Due to the fact that the scheme in CDR does not meet the requirements of high luminosity scheme, we have proposed a new design scheme for the injection system.

INJECTION PHILOSOPHY

Whether direct injection can be achieved depends on the common frequency of these major subsystems. The frequency choice in CDR is shown in Table 1, in which the SHB1 and SHB2 are the sub-harmonic buncher after the electron source. Due to the frequency of the Linac and ring in CDR did not match, so the common frequency is very small, only 13 MHz, with a minimum time step of 77 ns. while 38.461 ns can be achieved through some ingenious designs by the circumference adjustment. However, the requirement for the main ring at Z pole is between 20-28 ns, which does not meet the requirements. Apparently, it cannot meet the requirements for bunch number and results in 40% luminosity drop, so the whole scheme has to be modified. We consider replacing the subharmonic bunchers and the thermionic gun with photocathode RF gun so that the common frequency is raised from 13 MHz to 130 MHz, and the minimum time step becomes 7.692 ns. In addition, the minimum bunch separation in the collider ring can reach 23.076 ns by direct injection. Then, taking into account hardware, injection efficiency, and other factors, the entire injection timing was designed.

Table 1: Frequency Parameters

CEPC	SHB1	SHB2	Linac	DR	Booster	Collider
CDR	143	572	2860	650	1300	650
TDR	-	-	2860/5720	650	1300	650

INJECTION/EXTRACTION CHAIN

A traditional off-axis injection scheme is chosen as a baseline design of the beam injection to the collider ring, while a swap-out injection is given as an alternative only for Higgs operation. A schematic of the injection system is shown in Fig. 1 [3]. The injection system consists of a 20 GeV Linac, followed by a full-energy Booster ring. Electron and positron beams are generated in the Linac, and the positrons need to be injected in the DR firstly while the electrons passing through a bypass. The beams are then injected into the Booster and accelerated to full energy. After ramping to the required energy, both the electron beam and positron beam are injected into the Collider finally.

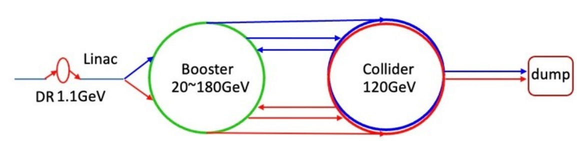

Figure 1: Injection and extraction system of CEPC.

Top-Up Injection

To maximize the integrated luminosity, CEPC will operate mostly in top-up mode. Electrons are generated from electron gun at 100 Hz. For High-Lum Z, more bunches are needed, it can be upgraded to 100 Hz double bunch or 200 Hz single bunch. The positron beam needs to be injected in the Damping ring(DR) first by 100 Hz / 200 Hz injection kicker. During each linac RF pulse a bunch/train is injected into the DR, after 4 bunches are stored, each bunch/train which is cooled after 20 ms will be extracted and re-injected into the linac. At the same time, a new bunch/train will be injected into the DR. The maximum bunch number in the damping ring is upgradable to 8 and hence the storage time can reach 40 ms to enhance the damping for each bunch. At the end of Linac, each bunch/train is injected into the booster by

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the 100 Hz / 200 Hz injection kicker. Figures 2 and 3 show the injection process from Linac to DR for two schemes of linac. And then these bunches are injected into the booster bunch by bunch at 100 Hz. And then ramp the booster up to given energy and all the bunches are extracted one by one by the 1000 Hz extraction kicker except for Z mode, and then injected into the collider, which are uniform in the half or whole ring both for booster and collider with certain separation. The injection parameters and timing structure for tt, Higgs and W energy mode are shown in Figs. 4, 5 and 6 respectively.

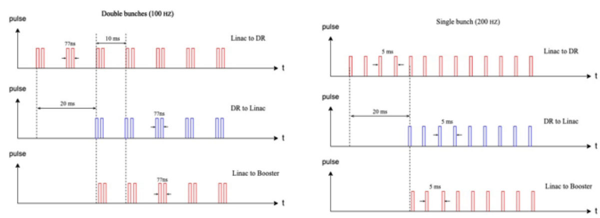

Figure 2: Injection process from Linac to DR.

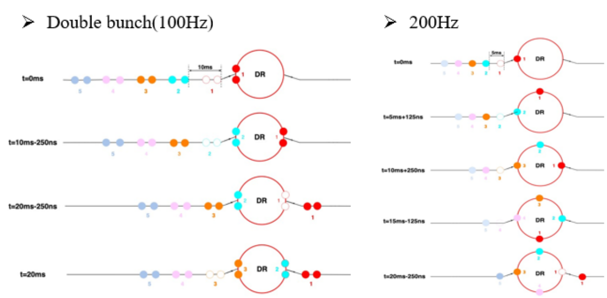

Figure 3: Time structure from Linac to Booster.

Injection to booster @ 20 GeV

	tt
Energy（GeV）	20
Bunch number	37
Bunch seperation（us）	4.2
Injection scheme	bunch by bunch
Kicker frequency(Hz)	100
Kicker pules duration (us)	<8.4
Kicker rise up/ fall down (us)	<4.2
Timing delay(us)	4.2
Injection duration (s)	0.37

Injection to collider @ 180 GeV

	tt
Energy（GeV）	180
Bunch number	37
Bunch seperation（us）	4.2
Injection scheme	bunch by bunch
Kicker frequency(Hz)	1000
Kicker pules duration (us)	<8.4
Kicker rise up/ fall down (us)	<4.2
Timing delay(us)	4.2
Injection duration (s)	0.037

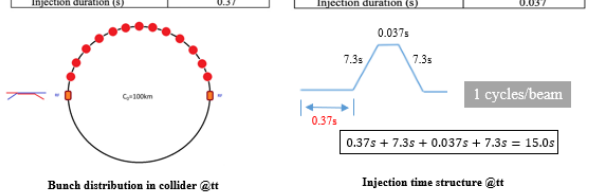

Figure 4: tt mode.

For Z energy, it becomes more complicated due to the large bunch number needed in the collider. Considering the rise time of the kickers,bunches are arranged train by train in the collider as shown in Fig. 7. The bunches in the collider are arranged in bunch trains about 1.85 µs and with gaps about 500 ns. The bunches in the booster are arranged in the same bunch train structure.But due to the current limit in the booster,the number of trains in the booster is only 1/3 of that in the collider,so the gap is much longer about 5.11 µs.

Injection to booster @20 GeV

	H
Energy（GeV）	20
Bunch number	240
Bunch separation（us）	0.647
Injection scheme	bunch by bunch
Kicker frequency(Hz)	100
Kicker pules duration (us)	<1.29
Kicker rise up/ fall down (us)	<0.647
Timing delay(us)	0.647
Injection duration (s)	2.4

Injection to collider @120 GeV

	H-off axis	H-on axis
Energy（GeV）	120	
Bunch number	240	7*
Bunch separation（us）	0.647	22.1
Injection scheme	bunch by bunch	bunch by bunch
Kicker frequency(Hz)	1000	
Kicker pules duration (us)	<1.29	<1.29
Kicker rise up/ fall down (us)	<0.647	<0.647
Timing delay(us)	0.647	22.1
Injection duration (s)	0.24	0.007

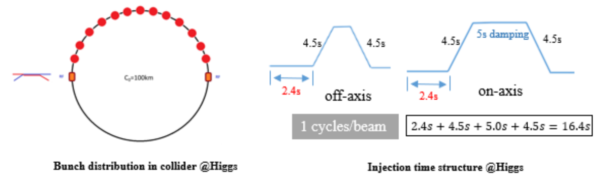

Figure 5: Higgs mode.

Injection to booster @20GeV

	W
Energy（GeV）	20
Bunch number	1230
Bunch seperation（us）	0.2677
Injection scheme	bunch by bunch
Kicker frequency(Hz)	100
Kicker pules duration (us)	<0.535
Kicker rise up/ fall down (us)	<0.2677
Timing delay(us)	0.2677
Injection duration (s)	12.3

Injection to collider @80GeV

	W
Energy（GeV）	80
Bunch number	1230
Bunch seperation（us）	0.2677
Injection scheme	bunch by bunch
Kicker frequency(Hz)	1000
Kicker pules duration (us)	<0.535
Kicker rise up/ fall down (us)	<0.2677
Timing delay(us)	0.2677
Injection duration (s)	1.23

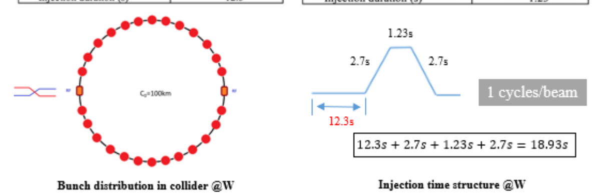

Figure 6: W mode.

There are 48 trains for each beam and 80 bunches for each train with the separation of 23.076 ns, so there are totally 3840 bunches in the booster. Figure 8 shows the schematic of the whole top-up injection for Z mode and the booster ramping scheme. All 3840 bunches are injected into the booster one by one (or two by two) in 19.2 s, and then the booster is ramped up to 45.5 GeV in 1.6 s. After that all bunches in booster are injected train by train into the collider by 1000 Hz extraction kicker. It takes three cycles for a single beam to be filled, so there are totally 11520 bunches in the collider ring,including 144 trains and each train 80 bunches,in which the bunch separation is 23.076 ns.

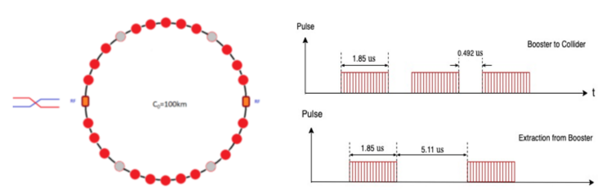

Figure 7: Bunch distribution in collider and time structure in booster and collider at Z pole.

Full Injection from Empty

More than that, the injection system needs to have the ability to fill the Collider from empty to full charge with a reasonable injection speed. We hope the injection process as quickly as possible, buy the total current in booster limited by RF system. And the beam lifetime in collider ring

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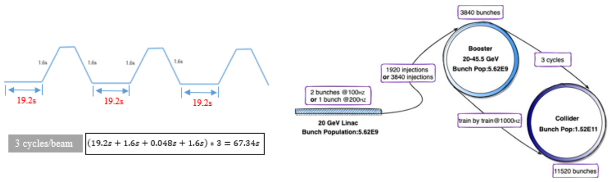

Figure 8: The process of booster ramping and top-up injection at Z pole.

without collision is dominated by the Toucheck lifetime and becomes much shorter with collision. Collision start after each beam is injected to full current independently. But at Z pole, the full injection adopts bootstrapping scheme [4, 5]. The collision start from 220 mA. Due to the beam-beam effects, the two beams are tightly grasped together, injecting and pulling at the same time. The bunch is lengthened slowly thanks to the beamstrahlung effect and the current in the collider ring rises bit by bit until it reach the design value. It takes 2 hours for both beams to reach full current, and the maximum limit current in the collider can reach 1 A. It takes 6min at tt mode, 10 min at higgs and 16 min for W mode to inject collider from empty to full current respectively. The variation of current in the collider with time is shown in Fig. 9.

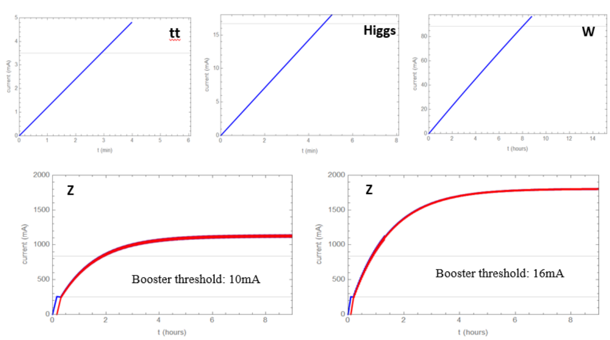

Figure 9: The variation of current in the collider with time.

UPGRAD CONSIDERATION

Considering the future 50 MW potential for Z operation, the bunch seperation which is required in the collider ring may be 16 ns. The minimum bunch seperation that can be realized in the main ring is 23 ns by uniformly filling under the improved frequency choice. Since the minimum time step due to common frequency is 7.69 ns, it is possible to fill the collider with unequal spacing, such as the combination of 7.69 ns, 15.38 ns and 23.07 ns. Moreover, flexible collocation can be realized between 15 to 24 ns with the uneven filling scheme.

CONCLUSION

The injection/extraction chain and timing structure of CEPC for four energy modes and different injection scheme have been designed with the consideration of clock system, RF frequency choice, bunch pattern, injection hardware and so on. However, considering the requirement of the injection bunch number and clock system, the RF frequencies in the Linac and accelerator rings are not compatible. Therefore, we modified the original scheme by replacing the subharmonic buncher and thermionic gun with photocathode RF gun, which basically meets our current design requirements and retains more flexibility for future high luminosity upgrade. Anyway, the discussion about timing and filling scheme for CEPC especially at Z pole is continuous and the injection philosophy still needs further optimization with the comprehensive consideration for technology, cost, upgrade potential and so on.

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