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THE PROGRESS IN PHYSICS DESIGN OF HEPS LINAC *

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Abstract

The High Energy Photon Source (HEPS) is a 6-GeV, ultralow-emittance light source to be built in China. The injector is composed of a 500-MeV Linac and a full energy booster. According to the study and commissioning consideration of on-axis swap-out injection system, a high bunch charge injector is desirable and a Linac that can provide 7nC per bunch electron beam to booster is needed. This paper present different bunching system schemes and the performance of different schemes are discussed.

INTRODUCTION

The High Energy Photon Source (HEPS) is a 6-GeV, ultralow-emittance storage ring light source to be built in China. The HEPS is composed of a 500-MeV Linac [1], a full energy booster [2] with 1 Hz repetition frequency, a 6-GeV storage ring [3] and three transport lines [4-6]. With the deepening of study and changes in requirements of the booster, the Linac has been iterated for several times [7]. The baseline design is a 500-MeV S-band normal conducting linear accelerator [1], which is composed of an electron gun, a bunching system and a main Linac. The electron gun can provide 4-nC per pulse 1.6-ns total length electron beam. The bunching system consists of a pre-buncher (PB), a buncher (B) and an accelerating structure with microwave frequency in 2998.8 MHz, which are driven by one klystron. The focusing element in bunching system is solenoid. The main linac consists of 8 accelerating structures, 5 triplets and 2 energy spread measurement systems. One klystron drives 2 accelerating structures. The Linac works in single-pulse mode with a repetition rate up to 50 Hz. The main parameters are shown in Table 1 and the layout is shown in Fig.1.

With the deepening study of on-axis swap-out injection [8, 9], higher bunch charge provided by the injector is desirable. On the other hand, considering the commissioning of the storage ring, if the injector can provide 5 nC electron beam per bunch, one can commission the storage ring effectively even without swap-out injection system at the first stage. So the required bunch charge at the Linac exit should be larger than 7 nC. With the injection simulation of the booster, the bunch number per pulse is best not exceed three. According to the requirements, one should redesign the Linac, especially the bunching system. So four schemes of bunching system are presented and discussed:

- Scheme I is the baseline design.
- Scheme II is adding a 166.6-MHz subharmonic cavity.
- Scheme III is adding a 499.8-MHz subharmonic cavity.
- Scheme IV is replacing the pre-buncher with a 499.8-MHz subharmonic cavity and a 166.6- MHz subharmonic cavity.

Table 1: Main Parameters of the Linac

Parameter	Unit	Value
Frequency	MHz	2998.8
Max Repetition Rate	Hz	50
Energy at the Linac exit	MeV	500
Bunch charge	nC	≥2.5
Normalized emittance	mm·mrad	40
Energy spread	%	0.5
Bunch number per pulse		3~5

PHYSICS ISSUES

Electron Gun

According to the new requirements of bunch charge, assuming the transmission efficiency of total Linac is about 70%, the electron gun should have the ability to provide 10 nC electron beam. With the high current operation experience of BEPCII electron gun, the total bunch pulse length is 1.6 ns and the full width at half maximum (FWHM) is 1.0 ns. The RF frequency of accelerating structure is 2998.8 MHz and the RF cycle is 333.5 ps. So the bunch pulse from electron gun is corresponding to 5 RF cycles. To obtain fewer bunch number the pulse length should be shorten.

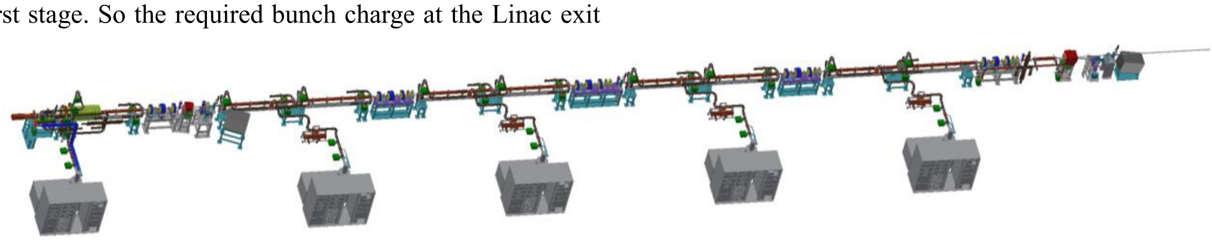

Figure 1: The layout of the Linac.

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Subharmonic Cavity

Normally, the subharmonic cavity can be used to reduce the pulse length. The frequency of the Linac signal generator is 499.8 MHz from the timing system, which generate the 2998.8 MHz signal by multiplying. To reduce difficulty of physical design, the frequency of subharmonic cavity adopts as 166.6 MHz by down-conversion and 499.8 MHz equal to signal generator, which named SHB1 and SHB2 respectively. The schematic and electric field distribution is shown in Fig.2.

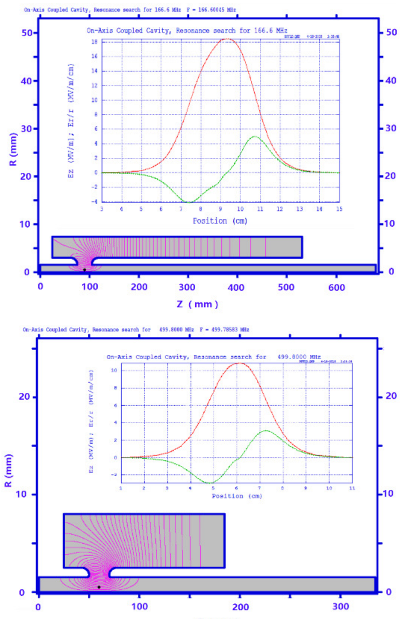

Figure 2: The schematic and electric field distribution of SHB1 (top) and SHB2 (bottom).

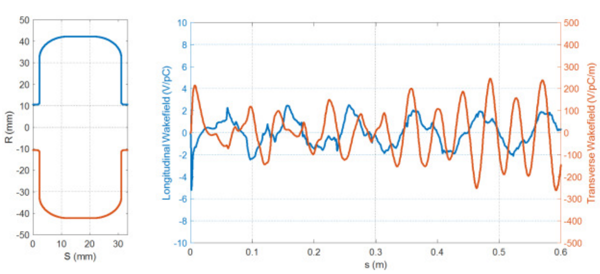

Figure 3: The cell shape and long-range Wakefield of one cell in accelerating structure.

Wakefield

The Linac with different bunching system scheme have different bunch number per pulse, meanwhile the pulse charge is very high, the Wakefield of accelerating structure is very important in the simulation of main Linac. The Wakefield includes short-range Wakefield and long-range Wakefield. The short-range Wakefield is obtained by analytical method [10, 11] and the long-range Wakefield is simulated by ABCI [12]. The cell shape and long-range Wakefield of one cell in accelerating structure is shown in Fig.3.

SCHEME DESIGN

Considering the physical and mechanical design of the baseline scheme have been finished, the design of main Linac is frozen. Our goal is want to meet the new requirements with minimal changes including the length and cost of the Linac. Based on this principle four schemes of bunching system have been presented. The Multi-Objective Genetic Algorithm (MOGA) have been introduced to optimize the bunching system to improve performance.

Scheme I is the baseline design without any hardware change. After some optimization the transmission efficiency of the bunching system is 94.1% including total beam, 88.6% including main five bunches and 62.7% including three bunches. The beam distribution at the Linac exit and beam orbit based on the five bunches beam is shown in Fig.4 including the Wakefields. The transmission efficiency of total Linac is 83.5% with energy spread in ±1.5% at Linac exit. For three bunches the transmission efficiency is about 60%. Because of high bunch charge and long-range Wakefield, the rear bunches affected by the front bunches, especially the beam orbit and energy. Considering the misalignment errors, the influence on transmission, beam orbit and emittance will further increase. This scheme cannot meet the requirements.

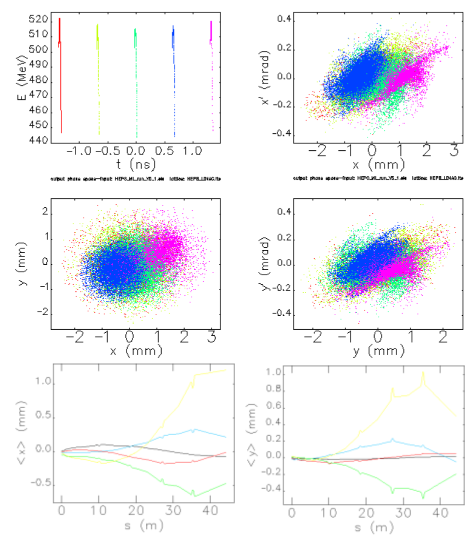

Figure 4: The beam distribution at the Linac exit (top) and beam orbit (bottom) of Scheme I.

Scheme II is adding a SHB1 with 166.6 MHz frequency, a BPM and four solenoids. The transmission efficiency of the bunching system is 92.7% including total beam and 88.7% including three bunches. Based on the three bunches beam, the transmission efficiency of total Linac is 77.8% with energy spread in ±1.5% at Linac exit. The beam distribution at the Linac exit and beam orbit is shown in Fig.5. According to the simulation results, the influence of long-range Wakefield is very large. Figure 6 shows the simulation results with misalignment errors and orbit correction. The bunch charge can meet requirements, but emittance growth is very large which mainly caused by the orbit distortion.

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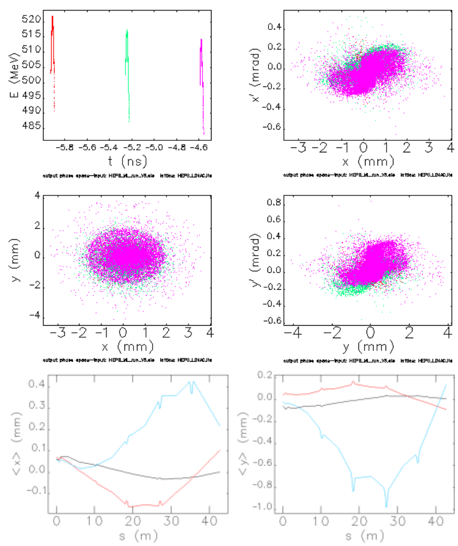

Figure 5: The beam distribution at the Linac exit (top) and beam orbit (bottom) of Scheme II.

Scheme III is adding a SHB2 with 499.8 MHz frequency, a BPM and two solenoids. The transmission efficiency of the bunching system is 94.4% including total beam, 82.4% including three bunches and 65.8% including one bunch. Based on the three bunches beam, the transmission efficiency of total Linac is 70% with energy spread in ±1.5% at Linac exit. The transmission efficiency is 63.2% for one bunch. Because of the long-range Wakefield the third bunch will be affected greatly by the two front bunches, the bunch charge of this scheme just meet the requirements of bunch charge.

Scheme IV is replacing the pre-buncher with SHB1 and

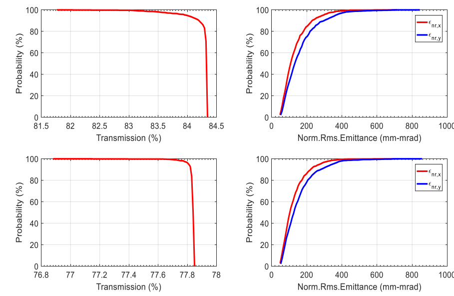

Figure 6: The transmission and emittance with misalignment errors and orbit correction. The top figures show the results of total beam and the bottom figures show the results of the beam within ±1.5% energy spread.

SHB2 and adding a BPM and five solenoids. The transmission efficiency of the bunching system is 97.9% including total beam and 96.2% including one bunch. Based on the one bunch beam, the transmission efficiency of total Linac is 88.2% with energy spread in ±1.5% at Linac exit and the emittance is 52 mm-mrad. This scheme can meet the requirements of bunch charge.

Recall the requirements, the bunch charge should be larger than 7 nC and the bunch number should be less than or equal to 3. Table 2 shows the comparison of different schemes. From the results, the scheme II and scheme IV can meet the bunch charge requirement, but for multiple bunches cases, the long-range Wakefield and errors will seriously affect the dynamic results, which cause large emittance growth and beam orbit distortion. Comprehensive consideration, the scheme IV is preferred. More optimization of the whole Linac based on scheme II and scheme IV are still going on.

Table 2: Comparison of Different Schemes

Parameter	**Unit**	**Scheme I**	**Scheme II**	**Scheme III**	**Scheme IV**
Element		PB+B	SHB1+PB+B	SHB2+PB+B	SHB1+SHB2+B
Increased number of solenoids		0	4	2	5
Increased length	mm	0	826	481	990
Bunch number		5/3	3	3/1	1
Bunch charge at Linac exit	nC	8.2/6	7.8	7/6.3	8.8
Energy spread	%	±1.5	±1.5	±1.5	±1.5
Emittance without errors	mm·mrad	62	55	65	52
Error influence on emittance		large/large	large	large/medium	medium
Error influence on orbit distortion		large/large	large	large/medium	small

CONCLUSION

With deepening of study, new requirements for the Linac have been put forward, such as high bunch charge and fewer number of micro-bunch. To meet the requirements, four schemes are presented and discussed in this paper.

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