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PROGRESS OF THE HEPS ACCELERATOR CONSTRUCTION AND LINAC COMMISSIONING*

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Abstract

The High Energy Photon Source (HEPS) is the first fourth-generation synchrotron radiation source in China that has proceeded on the track of construction. The accelerator complex of the light source is composed of a 7BA storage ring, a booster injector, a Linac pre-injector, and three transfer lines. In order to provide high-bunch-charge beams for the storage ring, the booster was designed to be capable of both beam acceleration from low injection energy to extraction energy and charge accumulation at the extraction energy by means of accepting electron bunches from the storage ring. The Linac was built using S-band normal conducting structures, and can provide electron beam with pulse charge up to 7 nC. This paper reports the progress of the construction of the accelerators, including the installation of the storage ring, the pre-commissioning tests of the booster, and commissioning of the Linac. In particular, the beam commissioning of the Linac will be introduced in detail.

INTRODUCTION

The High Energy Photon Source (HEPS) [1, 2] is the first fourth-generation synchrotron radiation source based on a 6-GeV diffraction-limited storage ring [3, 4] that is currently under construction in China. The accelerator complex of the HEPS comprises an injector and a storage ring. The injector consists of a 500-MeV Linac [5, 6], a full-energy booster [7], a low energy transfer line connecting the Linac and booster and two high energy transfer lines that transport beams between the storage ring and booster [8]. The layout of HEPS accelerator is shown in Fig. 1 and the overall design goals of the light source are listed in Table 1.

The storage ring consists of 48 modified hybrid 7BAs, which were grouped in 24 periods with circumference of 1360.4 m. The Booster consists of 4 FODO structure lattice with circumference of 454.07 m. The optical functions and layouts of the storage ring and booster are shown in Fig. 2. The swap-out injection scheme [9] is adopted, so the booster employs the "high-energy accumulation" scheme. In order to meet the requirements of the injection and beam commissioning, a high bunch charge scheme of the Linac was adopted [5] with bunch charge of 7 nC. The layout and tunnel of the Linac are shown in Fig. 2.

Considering the long injection interval in the ring, the injector adopts an energy-saving design, the Linac operates in burst mode, and the booster adopts a novel ramping-table-controlled scheme. For the burst mode of the Linac, each macro-RF pulse has 1 to 10 RF pulse and the RF pulse repetition rate is 50 Hz. The interval time of the macro-RF pulse is decided by the injection rate. For the booster ramping-table-controlled scheme, the booster can realize the stop and start at any energy. The power supply and the cavity can be ramped according to the ramping-table, every time there is a clock trigger, take a step, and wait without the clock trigger. The schematic diagram is shown in Fig. 3. When no injection is needed, the booster is in a low-power waiting phase without repeated ramping.

In this paper, we introduce the brief construction process of the HEPS, and present the latest results of beam commissioning.

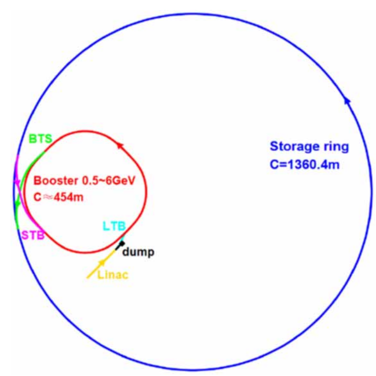

Figure 1: Layout of the HEPS accelerator.

Table 1: Main Parameters of The HEPS

Parameter	Value	Unit
Energy	6	GeV
Beam current	200	mA
Horizontal natural emittance	60	pm·rad
Brightness	>1x10^{22}	phs/s/mm^2/mrad^2/0.1%BW
Circumference	1360.4	m

CONSTRUCTION

Construction of the HEPS starts in June 2019 with a construction period of 6.5 years, which means it will be completed by the end of 2025. The milestone of the HEPS construction are as follows:

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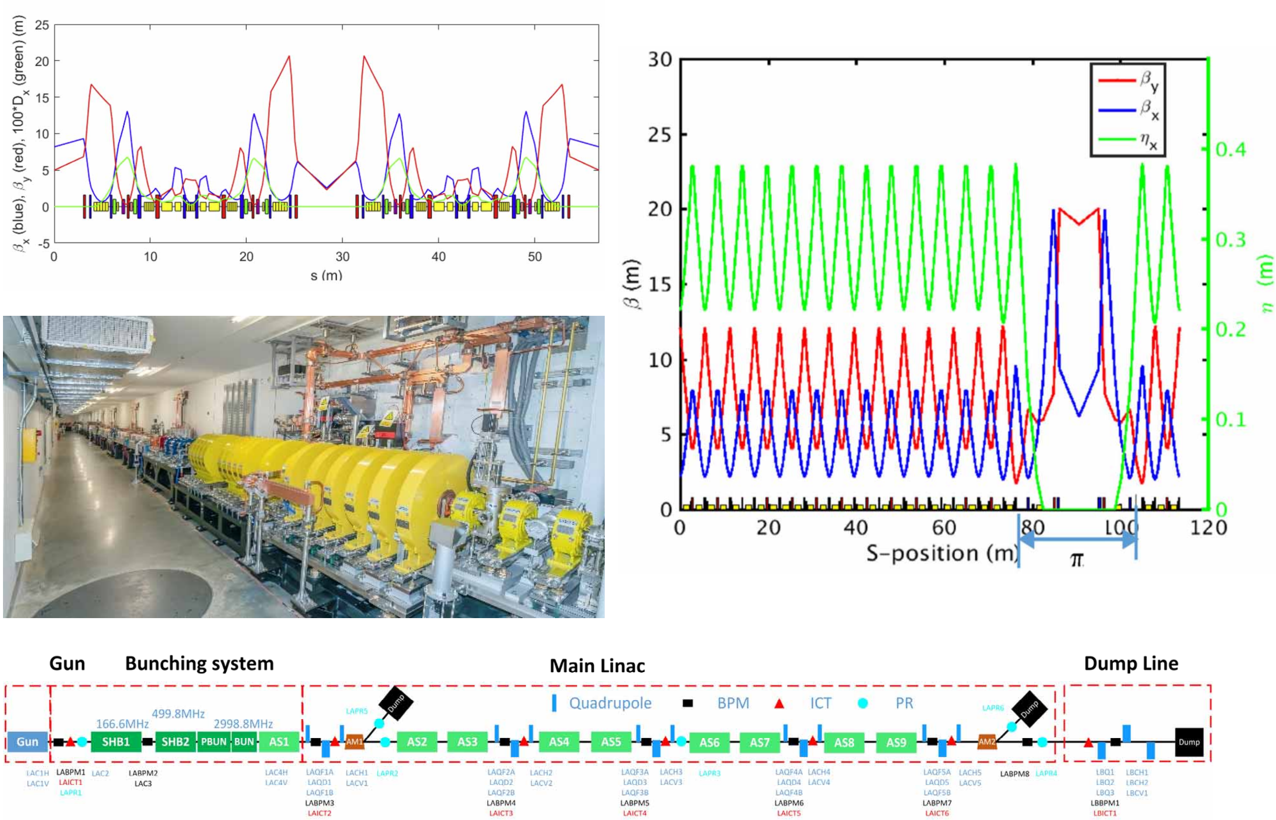

Figure 2: Optical functions and layouts of one super period of the storage ring (left-up) and booster (right-up), the tunnel (left-middle) and layout (bottom) of the Linac.

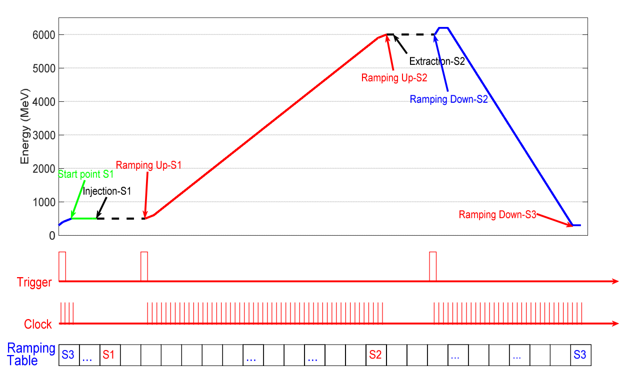

Figure 3: Schematic diagram of the booster ramping table.

- 2019.12, the physical design was frozen.
- 2021.06, installation of the first equipment.
- 2022.03, the tunnel installation of the Linac started pre-alignment installation of booster started.
- 2022.05, Linac full-line vacuum sealing was completed.
- 2022.08, the tunnel installation of the booster started.
- 2022.09, high-power online conditioning completed.
- 2023.01, booster full-line vacuum sealing was completed.
- 2023.02, the ring tunnel installation started.
- 2023.03, beam commissioning of the Linac started.
- 2023.06, completed process acceptance of the Linac.
- 2023.07, beam commissioning of the booster started.

The construction of the Linac has been completed and the process acceptance has been completed. The detailed beam commissioning will be introduced in the next part. The installation and system joint debugging of the booster has been completed and the beam commissioning is in progress, the energy has been successfully ramped to 6 GeV. The storage ring is in the intersecting process of equipment pre-alignment, tunnel installation, and tunnel alignment. At present, 60% of the tunnel alignment work of the magnet units has been completed.

COMMISSIONING

The Linac is a normal conduction S-band linear accelerator and composed of three sub-systems: an electron gun, a bunching system and the main accelerator. In terms of physical design, a complex bunching system was used to achieve a single bunch charge of up to 7 nC at the exit of the Linac. This is the highest bunch charge among linear (pre-)injectors for third and fourth generation light sources worldwide. Beam commissioning simulation of the Linac was completed in September 2021 [9]. A new platform, Python accelerator physics application set (*Pyapas*) [10] was developed and the beam commissioning applications of the Linac was completed [11].

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In early March 2023, we obtained the radiation protection permit for the Linac beam commissioning, and beam commissioning started on March 9, 2023. On that day, the first electron beam was observed on the first profile monitor at 10:28 am and the electron beam was successfully transferred to the end of the Linac at 12:15 am with beam energy reaching 500 MeV[13]. The strong space charge effect and wakefield effect brought by high bunch charge bring great challenges to beam commissioning [14]. We use the beam size optimization method and the wakefield free steering method to suppress the emittance growth. The distributions before and after optimization are shown in Fig. 4 and show strong short-range and long-range wakefield effect. After 3 months of beam commissioning, the test and acceptance of the Linac was completed. The measured parameters are shown in Fig. 5 and Table 2. Due to the high performance of the IGBT based solid-state modulator with pulse repetition stability of 0.02% and LLRF, the beam energy stability is better than 0.02%, which is shown in Fig. 6.

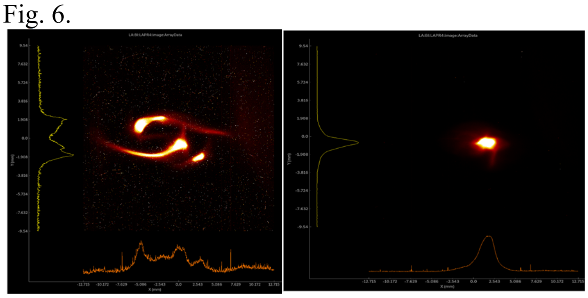
Figure 4: Beam distribution at the exit of the Linac with pulse charge of about 7 nC. Case one (left) have three bunch per pulse without optimization, Case two (right) have one bunch per pulse with optimization.

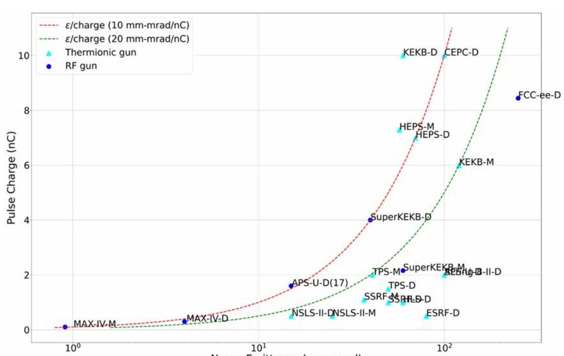

Figure 5: The bunch charge and emittance of different linear injectors.

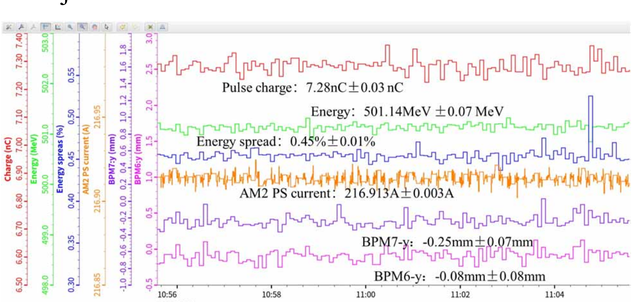

Figure 6: Stability of the Linac (mean ± std).

Table 2: Measured Parameters of The HEPS Linac

Parameter	Unit	Design		Measurement	
		Mode1	Mode2	Mode1	Mode2
Pulse charge	nC	≥2.5	≥7.0	2.84± 0.02	7.29± 0.02
Energy	MeV	≥500	≥500	501.4	501.2
Energy spread	%	≤0.5	≤0.5	0.31	0.45
Energy stability	%	±0.25	±0.25	σ=0.014 p-p=0.04	σ=0.014 p-p=0.05
Geometric emittance	nm·rad	≤41	≤70	37.2 (H) 36.9 (V)	56.4 (H) 58.5 (V)

The beam commissioning started since 25 July 2023. After 2 days injection commissioning, we saw the first synchrotron radiation light. Then we ramped the beam energy and reached to 6 GeV in 9 August, which is shown in Fig. 7.

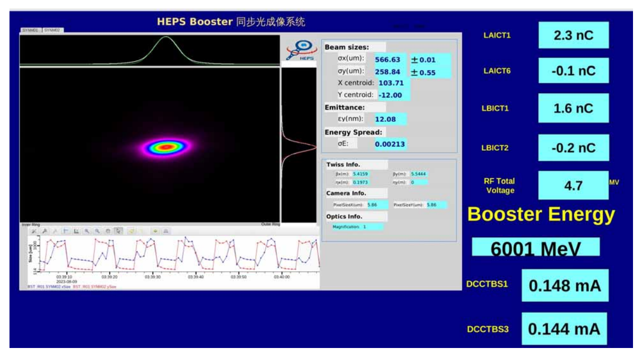

Figure 7: Synchrotron radiation light of the booster with beam energy of 6 GeV.

CONCLUSION

HEPS is the first fourth-generation synchrotron radiation source in China. The beam commissioning and process acceptance of the Linac have been completed. The beam energy has been ramped to 6 GeV and beam commissioning of the booster is in progress. The installation of the storage ring is progressing.

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