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CONCEPTUAL DESIGN OF HEPS INJECTOR *

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Abstract

The High Energy Photon Source (HEPS) will be constructed in the following few years. The light source is comprised of an ultra-low emittance storage ring and a full energy injector. The energy of the storage ring is 6 GeV. The injector is comprised of a 500 MeV linac, a 500 MeV to 6 GeV booster synchrotron and transport lines connecting the machines. In the present design, the linac uses normal conducting S-band bunching and accelerating structures. The booster adopts FODO cells, has a circumference of about 454 m and an emittance lower than 40 nm·rad. The injector can provide a single-bunch charge up to 15 nC at 6 GeV for the storage ring. This paper briefly introduces the conceptual design of the injector of the HEPS.

INTRODUCTION

The High Energy Photon Source (HEPS) will be constructed in the following few years. The facility is comprised of a storage ring and a full energy injector. The storage ring is designed to be operated at 6 GeV, and its lattice adopts a multi-bend achromatic (MBA) structure with an emittance lower than 60 nm·rad and an average beam current up to 200 mA in multi-bunch mode [1]. The dynamic aperture of the storage ring is only a few millimeters, which makes it difficult to accumulate charges in the ring using traditional injection schemes. An on-axis swap-out injection scheme is proposed for the storage ring. This injection scheme requires as high as 2 nC in a single bunch. This makes it difficult to build an injector providing such high single bunch charge with limited budget. Hence, the HEPS injector adopts linac plus booster synchrotron structure. The booster is used not only to ramp the beam energy to the extraction energy, but also to be a charge accumulator at the extraction energy. This paper reports the conceptual design of the HEPS injector.

OVERVIEW

In the present design, the injector is comprised of a linac, a linac-to-booster (LTB) transport line, a booster synchrotron, and two transport lines, the booster-to-storage ring (BTS) and storage ring-to-booster (STB) liness. The injector will be installed in different tunnels from that of the storage ring , as shown in Fig. 1. This arrangement is expected to significantly reduce the impact of the booster ramping on the beam dynamics in the storage ring.

The repetition rate of the injector is selected as 1 Hz. It can provide an electron beam with up to 10 bunches and

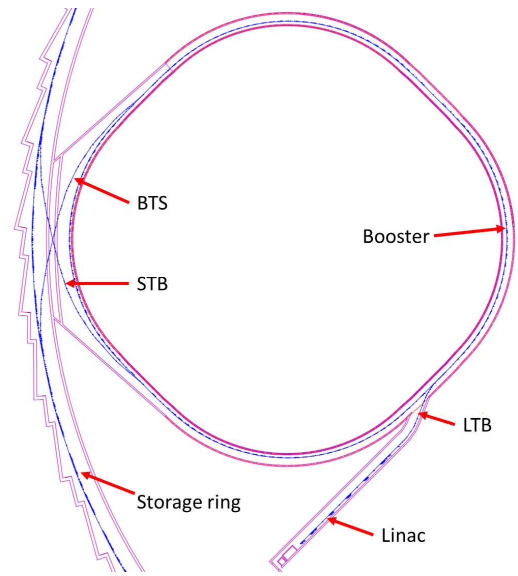

Figure 1: Layout of the HEPS injector.

2 nC in each bunch for storage ring. At the extraction energy — 6 GeV, the beam emittance and momentum spread of the booster are less than 50 pm·rad and 1×10^{-3} respectively, to achieve adequate injection efficiency for the storage ring. In order to achieve long term stability for operation, hardware systems based on mature technologies are employed in the design.

In the present arrangement, the electron beam from the electron gun is accelerated to 500 MeV by the linac, and injected into the booster via the LTB transport line. The booster then ramps the energy of the beam from 500 MeV to 6 GeV. A certain electron bunch in the storage ring is extracted and injected into the booster via the STB transport line, and merges with the beam already in the booster. The BTS transport line is used to transfer the beam from the booster to the storage ring.

THE LINAC

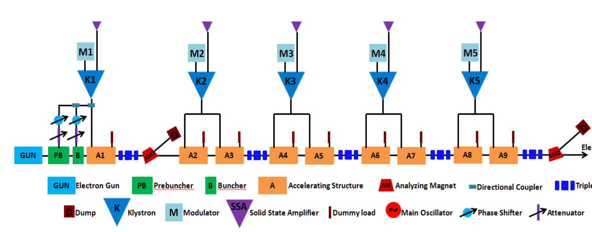

Figure 2: Layout of the HEPS linac.

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Table 1: Main Parameters of the Linac

Parameter	Units	Value
Microwave Freq.	MHz	2998.8
Max Repetition Rate	Hz	50
Max. Beam energy at the linac exit	MeV	500
Max Charge at the linac exit	nC	2.5
Width of macro-pulse (FWHM)	ns	1.1
Width of micro-pulse (RMS)	ps	5
Normalized emittance	μm · rad	40

The linac consists of an electron gun, a bunching section and a main accelerating section [2]. It works in single-pulse mode with a repetition rate up to 50 Hz. A thermionic electron gun is employed as the beam source. It works with a high voltage of 150 kV and can produce as high as 4 nC charges in each pulse. The bunching section includes a standing wave pre-buncher, a traveling wave buncher and a standard 3 meter-long traveling wave accelerating tube. The beam is accelerated to about 54 MeV at the exit of the bunching section. In the main accelerating section, 8 standard 3 meter-long accelerating tubes are used to boost the beam energy to about 500 MeV. There are totally 5 microwave power sources that are used to drive the bunching and accelerating structures. Among these power sources, one is used to drive the bunching elements, and the other four are used to drive the rest accelerating tubes. The arrangement of the microwave system is shown in Fig. 2. Table 1 lists some main parameters of the linac.

THE BOOSTER SYNCHROTRON

Besides providing "fresh" electrons for the storage ring, the booster also acts as an accumulator at the extraction energy. It produces a bigger bunch by combining the electrons extracted from the storage ring and from the linac, and sends the merged bunch back to the storage ring that after.

The Linear Lattice

The theoretical minimum emittance (TME) lattice, a fourfold 15-bend-achromatic structure, was originally adopted for the booster [1, 3]. The dipoles have transverse gradient, and the emittance can be reached as low as 4 nm·rad under this lattice. However, the momentum compaction factor is very small, less than 1×10^{-3}, limiting the maximum bunch charge at the injection energy due to collective effects. Then, a FODO lattice is adopted [3]. This lattice allows a larger momentum compaction factor (~4×10^{-3}) and a smaller average vertical beta function. This arrangement significantly increases the bunch charge threshold at the injection energy. As a price, the natural emittance of the booster at 6 GeV is increased from to 40 nm·rad, which still satisfies the demand of the storage ring injection.

The booster has four super-periods. Each super-period has 14 standard FODO cells in the middle and 2 matching cells at the two ends, as shown in Fig. 3. Each super-period has 32 dipoles, 37 quadrupoles and 17 sextupole. Table 2 lists its some critical parameters.

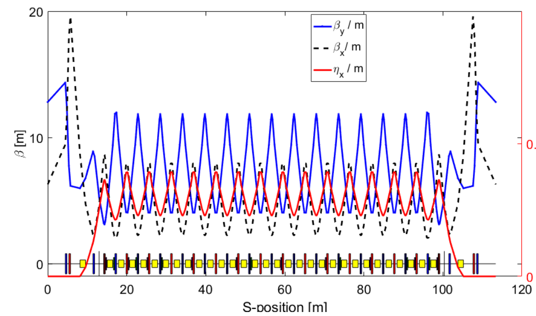

Figure 3: Optics of each super-period of the booster.

Table 2: Main Parameters of the Booster

Parameter	Units	Value
Circumference	m	453.5
Injection Energy	MeV	500
Extraction Energy	GeV	6
Repetition Rate	Hz	2.5
Emittance @ 6 GeV	nm · rad	37
Energy spread @ 6GeV		9.6×10^{-4}
Momentum compaction factor		3.8×10^{-3}
Tunes (ν_x, ν_y)		16.83, 10.73
Natural Chromaticity (ξ_x,ξ_y)		-18.5, -14.9
Maximum β_x, β_y	m	20, 15
RF frequency	MHz	500
Harmonic number		756

Injection and Extraction Schemes

The booster has a low energy injection system (LEIS) and a high energy injection system (HEIS). The LEIS is used to inject the beam from the linac to the booster, and the HEIS is for injecting the beam from the storage ring to the booster. Both of these injection systems use vertical injection scheme, i.e. the kickers provide vertical angles for the injecting beams. On-axis scheme [4] is used for the low energy injection, and only one kicker is in the LEIS. For the high energy injection, two kickers, separated by a phase advance π, are used to make orbit bump.

The extraction system of the booster also utilizes one kicker. To reduce the kicker strength, a slow bump generated by four small dipoles is used. These dipoles ramp with the main magnets in the booster cycles.

Lambertson type septa are used both for injection and extraction. Since this type of septum requires different height of beam orbits before and after the septum, the linac beam orbit is designed to be 2 mm lower than that in the booster. The vertical orbit position difference of the BTS and STB is produced by four vertical dipoles.

The linac provides beam in single bunch mode. There are two possible bucket filling patterns for the booster, evenly fills 2 or 10 bunches, respectively. The 2 bunch pattern is mainly for a high bunch charge mode operation of the storage

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ring, while the 10 bunch pattern is for typical multi-bunch mode operation.

Booster Magnets

Since the magnetic fields of the booster magnets ramp rapidly in a wide range, some important measures are taken into considerations to overcome the ramping induced problems. Firstly, the magnet cores will be fabricated using steel lamination to reduce the eddy current in the cores. Secondly, the number of turns of the coils is properly selected to avoid very high voltage and have moderate power consumption. Thirdly, the magnetic field is optimized both for low and high energies. Fourthly, the magnets are designed with a high uniformity, which is required by physics simulations. Fifthly, the ramping induced vibration is avoided or reduced by properly design the mechanical structure of the magnets, e.g H-type yokes are selected for the dipoles and correctors. Further more, installation issues are considered in the design.

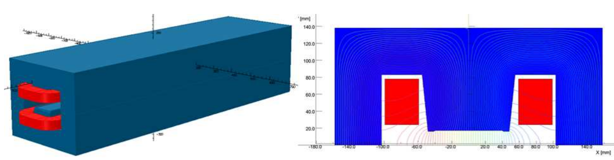

Figure 4: The physics model of the booster dipole.

Figure 4 shows the physics model of the booster dipole.

The RF System

The RF system of the booster is mainly used to accelerate the beam to the extraction energy, and compensate the energy loss due to synchrotron radiation. As the present design, up to 5 nC of charges are injected into the booster at 500 MeV in each cycle. This amount of charges are then accelerated to 6 GeV in about 400 ms, and need 27 W of RF power in this period of time. In the mean time, the synchrotron radiation induced energy loss increases with 4^{th} order of the beam energy, and reaches maximum at 6 GeV. This amount of energy needs about 13.3 kW RF power if the beam stay at 6 GeV. As a accumulator at 6 GeV, the maximum amount of charges in the booster is about 15 nC, and about 60 kW RF power is needed to compensate the energy loss. This is also the maximum RF power needed by the booster.

The PETRA 5-cell RF cavity is intent to be used in the booster. To provide enough RF power, 6 cavities are used in the booster ring. Table 3 lists main parameters of the RF system.

Eddy Current in the Vacuum Chamber

Since the magnetic field of the booster magnet ramps rapidly with energy, the varying magnetic fields generate eddy current in the vacuum chamber. To reduce the eddy current, 0.7 mm thick stainless steal is used for the vacuum chamber. The eddy current generated by the varying dipole field would produce strong sextupole field in the vacuum chamber nearby. Figure 5 shows the total amount of chromaticity change due the eddy current. This chromaticity change can be corrected by varying magnetic field of sextupole magnet.

Table 3: Main Parameters of the Booster RF System

Parameter	Units	Value
Frequency	MHz	499.8
Single cavity voltage	kV	≥8
Total power needed for the beam	kW	60
Power consumption of each cavity	kW	70
Maximum power needed for each cavity	kW	80
Number of cavities		6

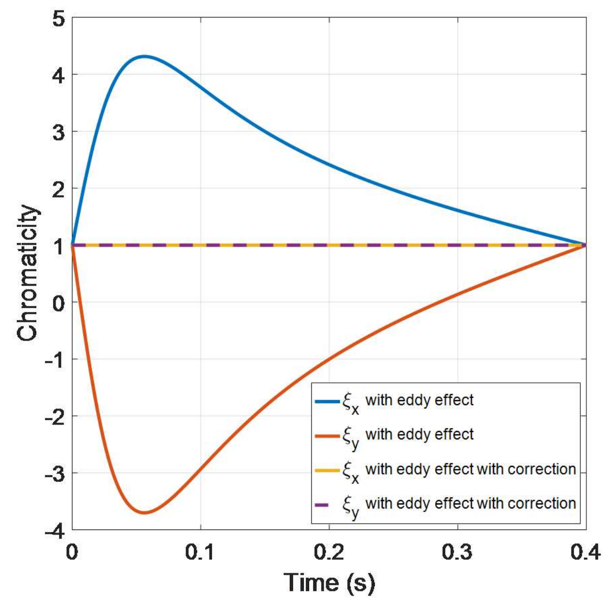

Figure 5: Eddy current induced chromaticity change.

THE TRANSPORT LINES

The LTB transport line is about 25 meters long. Its beta functions are designed lower than 40 meters in both x and y directions, and the horizontal dispersion function is below 0.5 meters. The twiss parameters at the injection point are matched with those of the booster. The lattice of the two high energy transport lines, the BTS and STB, are identical, both are about 102 meters long, and their beta and dispersion functions are lower than 50 and 0.19 meters, respectively. The vertical orbit in each of these transport lines is adjust using 4 vertical dipoles to meet the requirement of the Lambertson septum.

SUMMARY

The conceptual design of the HEPS injector has finished, and the preliminary design is undergoing. The construction of the facility will start at the end of 2018.

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