HIGH ENERGY TRANSPORT LINE DESIGN FOR THE HEPS PROJECT*

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Abstract

The High Energy Photon Source (HEPS), a kilometer-scale storage ring light source with the energy of 6GeV is to be built in China. For the injection scheme of the storage ring, on-axis injection is the baseline scheme. To simultaneously accommodate on-axis accumulation and swap-out injection schemes, we designed two high energy transport lines. In this paper we will report the detailed design of these two transport lines, including the layout and lattice design.

INTRODUCTION

The High Energy Photon Source (HEPS), a 6 GeV synchrotron radiation facility with ultralow emittance, is to be built in the suburbs of Beijing, China. An original hybrid 7BA design for the HEPS, with a natural emittance of 60 pm·rad and circumference of about 1.3km has been made [1].

The booster is a 4-fold symmetric ring with 4.5nm·rad natural emittance for the beam energy of 6 GeV[2]. Its circumference is 1/3 of the storage ring.

The very small dynamic aperture of the small-beta lattice design is not compatible with traditional off-axis injection schemes. So the on-axis injection is regarded as the baseline injection scheme. Two injection schemes have been considered: one is swap-out scheme, the other is on-axis longitudinal accumulation scheme. In the swap-out scheme, to eliminate the constraints of high charge to the linac, the booster will also be used for beam accumulation. So except the transport line which transports the beam from the booster to the storage ring(BTS), a transport line from the storage line to the booster has been designed to allow for accumulation of the extracted bunches from the storage ring in the booster at 6GeV(STB).

In the following we will introduce the transport line design in detail, including the layout and the lattice design.

LAYOUT OF THE TRANSPORT LINES

The main function of the high energy transport line is to effectively transport the beam between the booster and the storage ring. The BTS transport line transports the 6GeV electron bunches from the booster to the storage ring, the STB transport line transports the beam kicked out from the storage ring to the booster. To ensure the effective injection, the transport line has to match the Twiss parameters of the injection point. Moreover, the layout of the transport line is determined by the layout and position of the storage ring and the booster.

Since two transport lines are needed, the geometric constraint is more complicated than that of one transport line. The following constraints are imposed on the layout of the transport line.

- In order to avoid the impact on the storage ring from the booster, the distance between the storage ring and the booster should be large than 10m.
- The two transport lines should be as symmetric as possible.
- The conflict between physical equipment should be avoided.

To link the booster and the storage ring, first we should find the appropriate area to place the extraction and the injection system.

Beam is injected to the storage ring in the vertical plane. The injection system is composed of ten stripline kickers and one Lambertson. Limited by the available straight section length, the injected beam cannot avoid passing through the upstream quadrupoles. In order for the injected beam to stay near the accelerator midplane, a slightly tilted Lambertson septum magnet is used, giving a small vertical bending angle in addition to a relatively large horizontal bend. The main parameters of the injection components are listed in the Table 1. The extraction system of the storage ring is the same as the injection system.

Table 1: Main Parameters of Injection Elements

Title	Description	Values
Stripline kicker	Length	0.3m
	Kick angle	0.3mrad
Lambertson	length	1.6m
	strength	1T
	Tilt angle	115mrad
	Horizontal bend angle	79mrad
	Vertical bend angel	9mrad

The reinjection of the booster from the storage ring is off-axis injection scheme. Since the extraction of the storage ring is in the vertical plane, in order to keep the storage ring and the booster in the same horizontal plane, we also adopt the vertical injection scheme in the booster reinjection. It consists of four kickers and one septum. Four kickers are used to form a local orbit bump in the vertical plane. Meanwhile, the incoming beam will be deflected by a Lambertson horizontally. The whole injection system will be allocated in the same long straight section of the booster. The schematic layout is shown in the Fig.1. The upper one is the layout in the vertical plane while the lower one is in the horizontal plane. To keep the symmetry, the extraction system of the booster uses the same scheme with the reinjection system.

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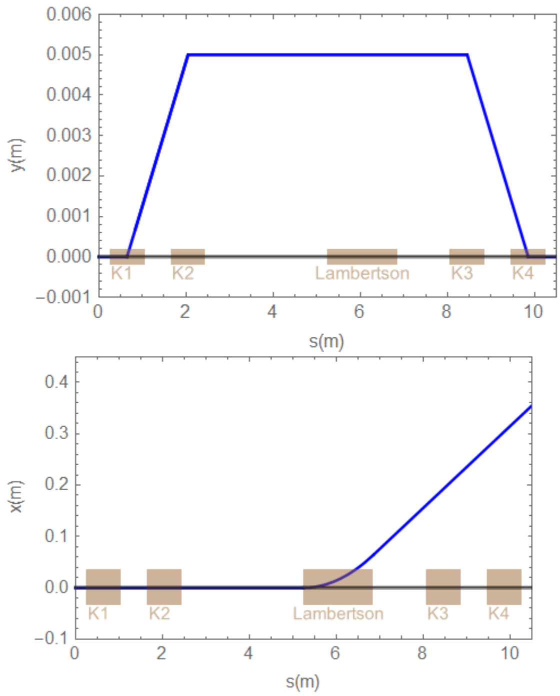

Figure 1: The schematic layout of the reinjection scheme of the booster.

Take the line between the center of the storage ring and the center of the booster as symmetrical line, we placed the injection and extraction system of the storage ring and the booster symmetrically. In the beginning, we considered placing the extraction system of the booster and the injection system of the storage ring at the same side of the symmetrical line, but the bend angle is too large and the technology of the normal bending magnet cannot satisfy. So we must place the extraction system of the booster and the injection system of the storage ring at the two sides of the symmetrical line, then the reinjection system of the booster and the extraction system of the storage ring are placed symmetrically. The layout of the two transport line is shown in the Fig.2. To keep the enough distance between the storage ring and the booster, we chose the second straight section of the storage ring from the symmetrical line as the injection and extraction section. The center of one period of the booster is on the symmetrical line. Except extraction Lambertson and injection Lambertson, the total bending angle of the transport line is 983 mrad, which is equally divided into 14 bending dipoles with a deflection angle of 70.1mrad each. Since there is a 6mrad angle in the vertical plane at the exit of the extraction of the storage ring, we use three vertical bending magnets to keep the storage ring and the booster in the same horizontal plane. Fig.3 shows layout of the transport line in the vertical plane. The maximum vertical distance between the transport line and the storage ring is 0.19m.

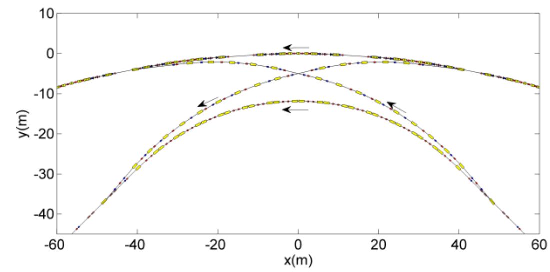

Figure 2: The layout of the two transport line.

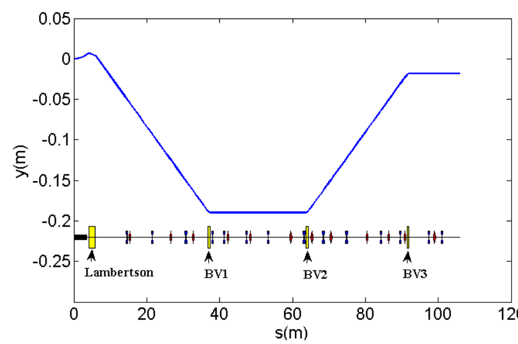

Figure 3: The layout of the two transport line in vertical plane.

LATTICE DESIGN OF THE TRANSPORT LINE

Since the two transport lines are completely symmetric, here we take the STB transport line as an example to show the lattice design. The STB transport line is defined between the exit point of the storage ring and the booster injection point which is located at the exit of the injection Lambertson. The beamline has been partitioned into three sections, which are briefly discussed below.

- The extraction section: This section of the beamline contains, the extraction devices, (extraction kicker, and extraction Lambertson), five dipoles and seven quadrupoles. These quadrupoles serve to generate an achromatic section and adjust the beam parameters at the end of the extraction section.
- The achromatic section: This section of the beamline follows the extraction section, and consists of four quadrupoles. This section is to be used for measuring the beam emittance and the beam parameters.
- The injection section: This is the last section of transport line, the function of this section is to match the transported beam to the circulating beam of the booster at the injection point. It consists of nine dipoles, the injection septum and the injection kicker. It also includes 15 quadrupoles for the required beam matching at the injection point.

Beam Constraint along the Transport Line

The main beam constraints of the transport line is to transport the extracted beam from the storage ring to the booster and match the beam parameters of the beam at the Injection point to those of the circulating beam. The optimal vertical beta functions of the transport line at the

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injection point β can be derived by solving the following equation[3]:

$$\beta_i^{\,2} + \left(\frac{n\sigma_i + T}{2\sqrt{\varepsilon_i}}\right)\beta_i^{\frac{3}{2}} = \frac{\beta_0^{\,2}}{2}$$

Where ε_i is the vertical emittance of the injected beam, β_0 is the vertical beta function of the stored beam at the injection point, $n\sigma_i$ is the horizontal size of the injected beam at the injection point and T is the effective septum width. Applying the beam parameters at the injection point, the optimum vertical beta function β_i of the transport line at the injection point is 0.675 m.

The following additional constraints are also imposed on the transport line.

- The maximum values of the horizontal and vertical beta function along the line should be less than 50 m ($\beta_{x,y}$<50 m). Similarly the absolute value of the horizontal dispersion function should be below 1.2 m ($|\eta_x|$<2 m) at any point along the line.
- The "achromatic section" of the line is designed to provide an achromatic beam in both the horizontal and vertical directions. This section of the line will be used to characterize the transported beam by measuring its emittance and the beam parameters. The beam characterization can be performed by utilizing the Nominal settings of the quadrupoles that are used to transport the beam or by altering the settings of the quadrupoles.

Beam Optics of the Transport Line

The beam optics of the transport line must satisfy the constraints mentioned earlier. The design of optical functions is shown in Fig.4. The beam-stay-clear are also estimated in both horizontal and vertical planes of 5σ + 5mm with the assumption of full coupling. Fig.5 shows the beam-stay-clear of the transport line.

CONCLUSION

As described above, we have designed two high energy transport line to keep the compatibility of the swap-out injection and considered the geometry constraint adequately to make these two transport lines as symmetric as possible. Actually, for the booster extraction the on-axis extraction scheme can be realized, so more studies are needed to achieve an optimal design for the high energy transport line.

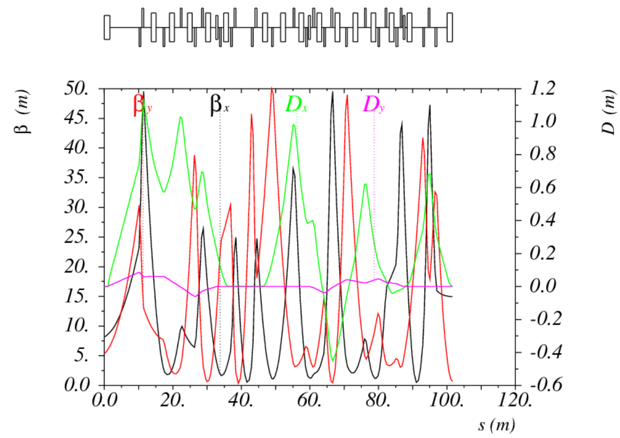

Figure 4: The Twiss function of the transport line starting from the extraction Lambertson.

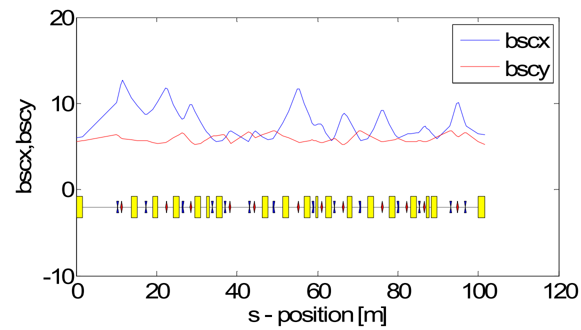

Figure 5: The beam-stay-clear of the transport line.

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