THE OFF-AXIS INJECTION LATTICE DESIGN OF HEPS STORAGE RING*

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Abstract

The dynamic aperture size determines the injection scheme to a large extent. The aim of storage ring design of HEPS is to achieve ultralow emittances on both transverse planes. This will bring very strong lattice nonlinearities. The present nominal design is a hybrid 7BA design with effective dynamic aperture of about 3 mm both in horizontal and vertical plane. Due to the restriction of dynamic aperture of this lattice, on-axis injection is the only choice. But, on-axis injection will bring a very big challenge for injector or injection kicker, if it is feasible to obtain a large dynamic aperture, off-axis injection is a favoured choice. In this paper, we will show the preliminary study of the lattice design with a sufficient dynamic aperture for pulsed multipole injection.

INTRODUCTION

A kilometre-scale storage ring light source with transverse emittances below 100 pm.rad, named HEPS (High energy Photon source), is proposed to be built in suburbs of Beijing, China. The present nominal design [1] is a 48-fold hybrid 7BA design with efficient dynamic aperture about 2.5 mm in horizontal plane and 3.5 mm in vertical plane, which is not compatible with an off-axis injection scheme. On-axis injection is thought as the only choice.

Many on-axis injection schemes were proposed in ultralow emittance light source designs. APS-U [2] and ALS-II [3] will use the on-axis swap-out injection scheme [4]. This injection scheme requires that the injector is able to provide a high-charge bunch to replace an existing stored bunch, a full-charge injector is essential and the proper treatment of the dumped beam needs a serious consideration. Aiba proposed the longitudinal injection with a shifted phase and a little higher energy compared to the circulating beam [5], which requires a large momentum aperture (MA) and stringent control of phase and energy jitters. On-axis longitudinal injection scheme based on an active double-frequency RF system was proposed [6] which brings a very challenge for injection kicker and RF system.

Based on the consideration of an accelerator design, it is better to use mature technology if possible, to reduce potential risk in the construction, commission and operation of the machine. Off-axis injection is still a favoured choice. Besides using conventional pulsed kickers or pulsed multipoles, has been demonstrated and used on existing machines, it reduced the compatibility of injector design. Thus, a design with specially designed high-beta straight sections was developed.

In this paper, we will introduce the requirement of this design, then present a preliminary design, and give a brief summary in the last.

LINEAR OPTICS DESIGN

HEPS is a green-field machine, compared to upgrade project of existing light sources, the lattice design isn't limited by the existing tunnel and the reuse of hardware. There is larger space for the variations of the parameters and less constraints, so, it is flexible for the HEPS design. Here are several optics design constraints:

- A natural emittance below 100 pm at 6 GeV with a circumference about 1.3-1.4 km,
- Large than 6 m straight sections for insertion device (ID),
- Large than 10 m straight sections for off–axis injection system,
- Vertical beta functions at IDs close to 3 m,
- Horizontal beta functions at IDs not too large (< 10 m) to improve brightness,
- Sufficient injection aperture in long straight section for off-axis injection,
- Sufficient MA for Lifetime at 200 mA.

The nominal design almost meets all the requirement except the dynamic aperture. To enlarge the DA, except optimizing the multipole sets, it seems necessary to increase the beta functions at the straight section. One way is to design the lattice with alternatively distributed low and high-beta straight sections as in [7]. The drawback of it is that only half of the straight sections were designed with low beta functions for optimal matching of the electron and photon beam. Another way is to design the lattice with a few specially designed high-beta sections. To restore the periodicity, the phase advance of the high-beta section was tuned to be same as that of a normal section, or with a difference of $2n\pi$ (n is integer) (see, e.g., [8]). In this way, one can obtain large DA for off-axis injection and simultaneously keep as many low-beta straight sections as possible for optimal ID emission. Nevertheless, the drawback is that the periodicity holds only for the on-moment particles. The more the momentum deviation is, the more the periodicity will be destroyed. The consequence is usually a smaller momentum acceptance than that of a design consisting of identical MBAs.

The off-axis injection system only needs one long straight section, but for survey consideration, the opposite straight section is also needed to be increased to nearly

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the same length. Based on a design similar to the present nominal design, we increase the length of two opposite straight sections from 6 m to larger than 10 m, and add two additional quadrupoles (grouped in one family) in each straight section. By varying the quadrupole strengths, positions, and the long straight section length of the specially designed section, the horizontal beta function is increased to about 90 m for the convenience of off-axis injection (see Figure 1), and in the opposite long straight section the beta functions are kept below 15 m for the convenience of place RF cavities there (see Figure 2). The main parameters of this lattice are listed in Table 1.

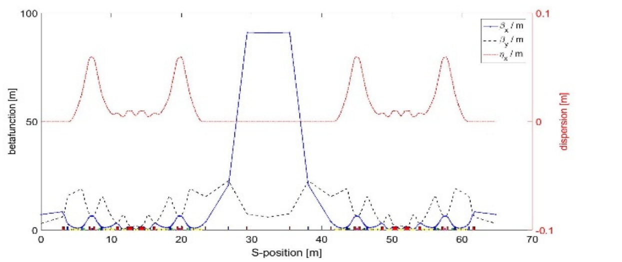

Figure 1: The straight section with horizontal beta of 90 m for the convenience of off-axis injection.

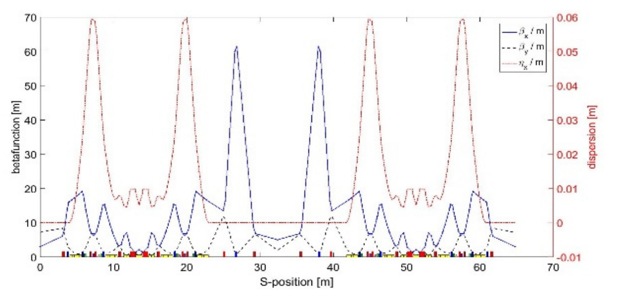

Figure 2: The opposite straight section with horizontal beta below 15 m for the convenience of installing RF cavities.

Table1: Main Parameters (SS: Straight Section)

Parameters	units	values
Circumference	m	1317.3
Emittance	pm.rad	60.2
Tune		112.284/41.143
Natural chromaticity		-137.09/-140.02
Straight section	m	6*46+10*2
Beta functions in 6 m-SS	m	7.20/3.07
High beta in 10 m-SS	m	90.86/5.99
Low beta in 10m-SS	m	1.96/5.02
Energy spread		8.5827E-4
Momentum compact factor		3.14E-5
RF frequency	MHz	499.8
RF voltage	MV	3.4
Bunch length	mm	2.56

NONLINEAR OPTICS OPTIMIZATION AND PERFORMANCE

Up to now, we do not re-optimize the multipole setting, while only multiply all the sextupole strengths by such a factor that the corrected chromaticity are greater than (+0.5, +0.5). As shown in Figure 3, the effective DA at the center of the high-beta section is ~9 mm in x plane and ~6 mm in y plane (a preliminary study shows that the DA with errors is in a similar size, the result is shown in Figure 4), satisfying the DA requirements of pulsed multipole injection, and the tunes are kept within integer and half integer resonances for the momentum deviations ranging from -3% to +3%.

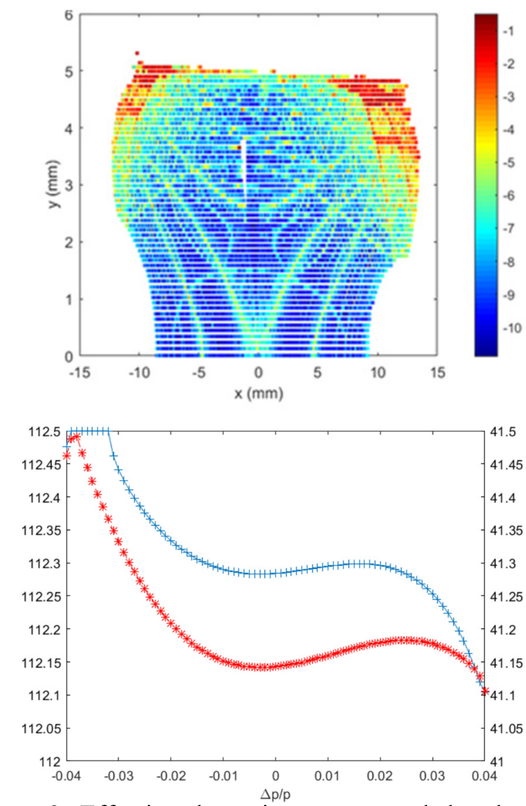

Figure 3: Effective dynamic aperture and the chromatic curves at the center of the high-beta straight section.

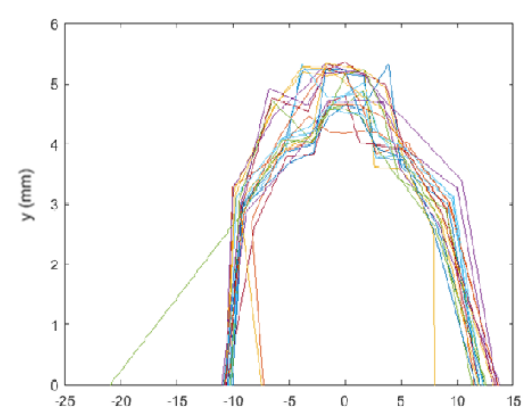

Figure 4: Dynamic aperture with errors at the center of the high-beta straight section (20sseds).

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Nevertheless, further simulation including RF (assuming 3.5% bucket height) and synchrotron radiation effects shows that the effective MA at dispersive region is much smaller, only ~1.5%, as shown in Fig. 5. Considering RF cavities of 500 MHz and 1.5 GHz and beam current of 200 mA uniformly distributed in 90% of the buckets, the bunch length is about 10 mm and the Touschek lifetime is about 3.5 hrs.

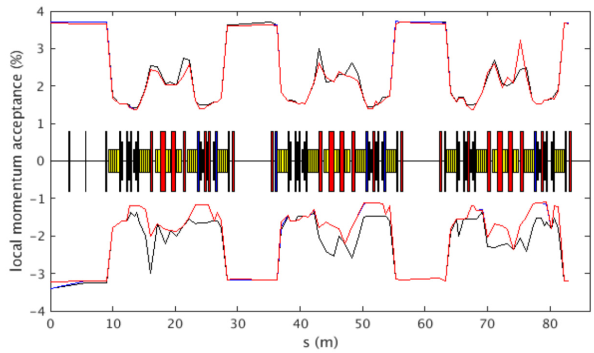

Figure 5: Local momentum acceptance along three 7BA cells of the HEPS design with high-beta straight section. In the calculation, the bare lattice is used, and RF cavity and synchrotron radiation are turned on. Three criterions determining the MA are considered, i.e., particle loss in 2000 turns (black), particle loss or crossing integer resonances (blue), particle loss or crossing integer and half integer resonances (red).

We are concerning whether the small MA at dispersive region is related to the high-beta section. Another lattice was designed in the same way but with the largest horizontal beta function reduced to 60 m. In this case, the effective DA is slightly smaller, ~6 mm in x plane (see Fig. 6), but the effective MA at the dispersive region is increased slightly (see Fig. 7), the estimated Touschek lifetime, this time, is about 5 hrs. This suggests that there is probably an 'optimal' value of the beta function at the injection section which promises both a large enough DA for off-axis injection and large enough LMA for a long enough Touschek lifetime. Besides, globally re-optimization of the multipole strengths (possibly grouped in more families) is not done yet, which may be helpful to reach this goal.

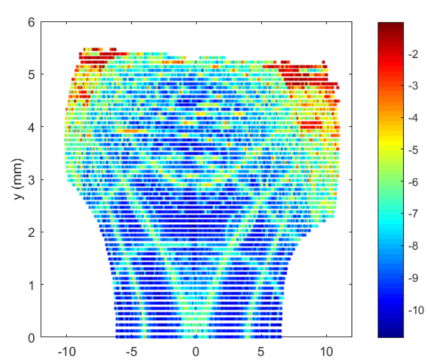

Figure 6: Effective DA at the high-beta straight section with high beta straight section (maximum β_x= 60 m).

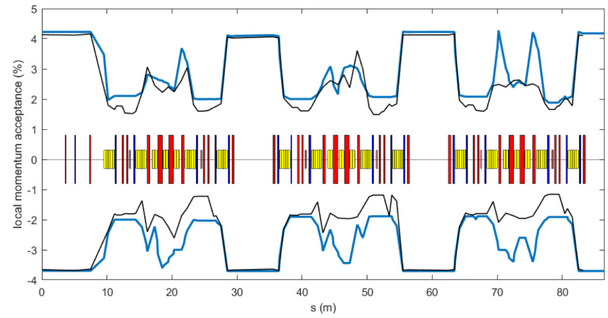

Figure 7: LMA along three 7BA cells for the HEPS design with high-beta straight section .Blue curve: LMA of the bare lattice. Black curve: Effective LMA of the bare lattice.

CONCLUSION

Base on the baseline design, we give a preliminary design with sufficient DA for off-axis injection. The high –beta section brings a greater DA, but, at same time, it affects the MA at dispersive region and reduce the Touschek lifetime. The next step we will continue to optimize the beta function of the high-beta straight section and the sextupole strengths to get a lattice with large enough DA for off-axis injection and a larger MA about 3% for longer Touschek lifetime.

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