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DESIGN STUDY OF HEPS BOOSTER DESIGN*

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Abstract

The High Energy Photon Source (HEPS) is a 6GeV ultra-low emittance light source proposed to be built in Beijing. It will utilise a full energy booster synchrotron operating at a frequency of 1Hz as its injector. For meeting the requirement of high charge when using swap-out mode, the booster need to have the ability of beam accumulation. In this paper, a FODO lattice with 4 dispersion-free straight sections is presented.

INTRODUCTION

The light source HEPS with emittance less than 0.1nm.rad is proposed to be built in the suburb of Beijing. It will be composed of four main parts, a 0.3 GeV linac as the pre-injector, a full energy booster to accelerate the electrons from 300 MeV to 6 GeV, a storage ring at 6 GeV and the radiation synchrotron experimental hall.

The booster is located in a separate tunnel with a circumference about 453.5 m, 1/3 of that of the storage ring. It raises the energy of a 300 MeV electron beam up to 6 GeV in approximately 400 ms and operates at repetition rate of 1Hz.

Two filling patterns are mainly considered in HEPS storage ring, high-brightness mode (or low-bunch-charge mode, 90% buckets uniformly filled by about 680 bunches with beam current of 200 mA) and timing mode (or high-bunch-charge mode, 63 bunches uniformly filled in the ring). For the latter filling pattern, we need inject about 14nC charge to each bucket, this is a big challenge for injector, and so, the booster also used for beam accumulation is proposed.

For meet the storage ring operation requirements, the booster need support the beam with 2nC single bunch charge. The high bunch charge is a big challenge when beam energy is 300MeV.Under the detailed instability analysis, we change the booster lattice from TME cell with combined dipole [1] to FODO cell with separated dipole for larger momentum compact factor.

This paper is entirely about the lattice design and beam dynamics of the booster.

LATTICE DESIGN

The booster employs a classical FODO lattice structure as standard cell. It is a four-fold symmetry lattice with 14 identical cells together with two modified cells containing dispersion suppressors. The booster lattice is presented in Figure 1.The circumference is about 453.5 m, 1/3 of that of the storage ring.

There are four 8-m long straight sections with dispersion-free suitable for the installation of RF cavity, injection, and extraction systems. The main parameters are listed in Table 1.

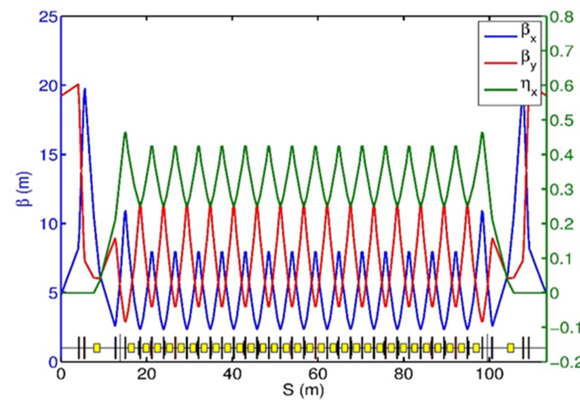

Figure 1: Optical functions and lattice structure of quarter.

Table 1： Main Parameters of HEPS Booster Lattice

Parameter	Unit	Value
Injection energy	GeV	0.3
Extraction energy	GeV	6
Number of super-periods		4
Length of the straight sections	m	8
Circumference	m	453.5
Repetition rate	Hz	1
Emittance @ 6 GeV	nm.rad	43
Emittance @ 0.3 GeV	nm.rad	70
Tune(H/V)		16.30/10.73
Energy spread @ 6 GeV		9.6×10^{-4}
Energy spread @ 0.3 GeV		0.5%
Natural chromaticity(H)		-17.70
Natural chromaticity(V)		-14.70
Momentum compaction factor		4.2×10^{-3}
Energy loss per turn @ 6 GeV	MeV	4
Long. damping time @ 6 GeV	ms	4.56
Hor. damping time @ 6 GeV	ms	4.51
Ver. damping time @ 6 GeV	ms	2.24
Maximum β_x	m	19.8
Maximum β_y	m	20.1
Maximum dispersion	m	0.5

We use six families of chromatic sextupoles to correct the chromaticity and nonlinear optimization. The nonlinear dynamics is simulated with AT program. The dynamic aperture of bare lattice and physical aperture in the middle of long straight is presented in Figure 2. The horizontal and vertical aperture can meet the requirements of beam

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stay clear and tousheck lifetime. The chromaticity curve is shown in Figure 3, and the transverse momentum acceptance is about 2.8%.

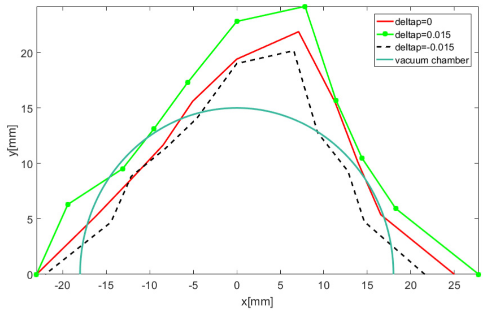

Figure 2: The DA in middle of long straight without error.

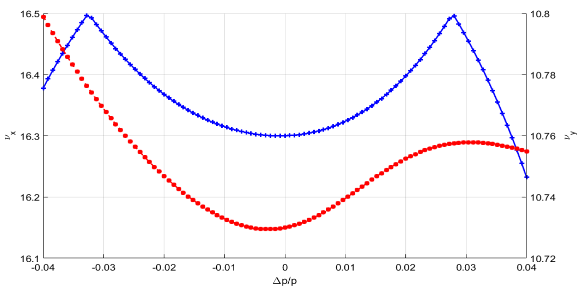

Figure 3: The chromaticity curves of HEPS booster lattice.

ANALYSIS OF RAMPING PROCESS

Ramp Cycle

HEPS booster operates with repetition rate of 1Hz, a ramp cycle is shown in Figure 4. The ramping curve has a flat bottom of 200 ms for 10 bunches injecting to booster from the linac, and also a flat top of 200 ms to allow the bunch inject to booster from storage ring merge to the bunch already in the booster at 6GeV and extraction to storage ring, 400ms for energy ramping up and 200ms for energy ramping down.

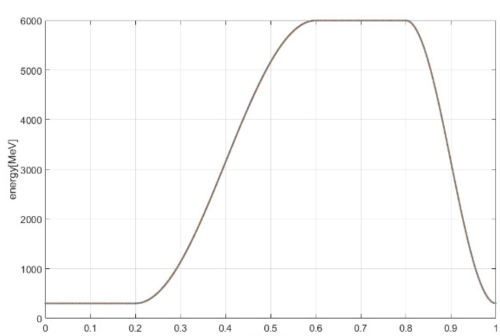

Figure 4: An energy ramp cycle in the booster.

Eddy Current Effect

Magnetic field ramping in booster induces eddy current in the dipole vacuum chambers. This produces an effective sextupole field superimposed on the nominal dipole fields, leading to changes in the chromaticity. The sextupole strength inside the vacuum chamber due to the eddy currents is calculated by the formula given in ref.[2] .We consider using a stainless steel vacuum chamber of height g =30 mm and elliptical aspect ratio g/w = 0.75, the thickness of vacuum chamber is 0.7mm, with these element parameters, we can get the sextupole strength induced by eddy current in ramping up process like shown in Figure5, the maximum value of the sextupole field is about 0.08m^{-3}.

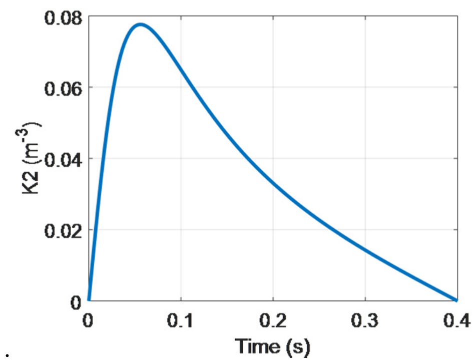

Figure 5: The sextupole strength induced by eddy current in ramping up process.

Corresponding calculated values of chromaticity are +3.3 horizontally and –4.7 vertically, which can be compensated by local modification of the sextupole ramp. The chromaticity evolution curve and the strength of compensate sextupole is shown in Figure 6.

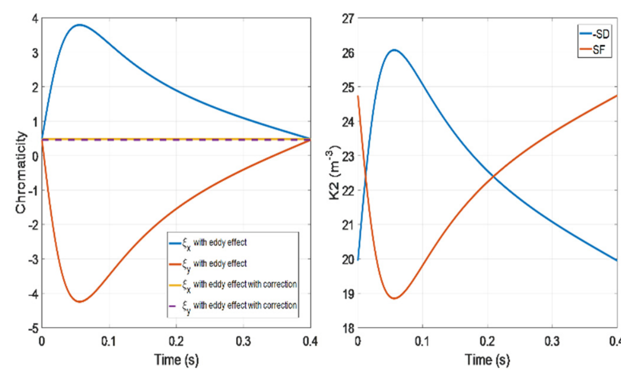

Figure 6: The curves of chromaticity evolution and strength of compensate sextupole.

Emittance and Energy Spread Evolution

Beam energy spread and emittance evolution with energy ramping can calculate by the formula [3]

$$\frac{dA_i}{dt} = -A_i\left(\frac{\dot{E}}{E} + J_i\frac{P_\gamma}{E}\right) + C_q\frac{P_\gamma \gamma^2}{E}G_i \quad , \quad (2)$$

where A_i with i = 1 and 2 represents the energy spread $(\sigma_E/E)^2$ and horizontal emittance ε_x, respectively. The first two damping terms in right hand side come from the adiabatic damping process which results from the evolution of the beam energy and the effect of radiation damping, and the last excitation term comes from the quantum fluctuation. J_i is the damping partition number, J_1 is the longitudinal damping partition, J_2 is the horizontal damping partition number. $P_\gamma$is the synchrotron radiation pow-

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er, C_q=3.83*10^{-13}m. G_1=I_3/I_2, G_2=I_5/I_2, I_2, I_3 and I_5 are the synchrotron radiation integration. The emittance and energy spread evolution are given in Figure 7.

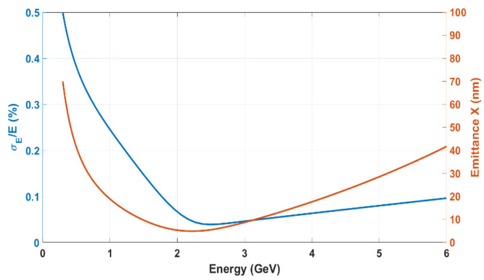

Figure 7: Emittance and energy spread evolution in ramping.

RF Cavity

There are six 5-cell 499.8MHz RF cavities placed in the booster which offer 6MV voltage and support 0.6% bucket height in extraction energy.

At injection energy, we set the RF voltage 1.2MV. The RF voltage ramping up curve is set like Figure 8, the RF voltage linear ramp from 1.2MV to 6MV in 300ms, and then hold in 6MV until the beam is extracted.

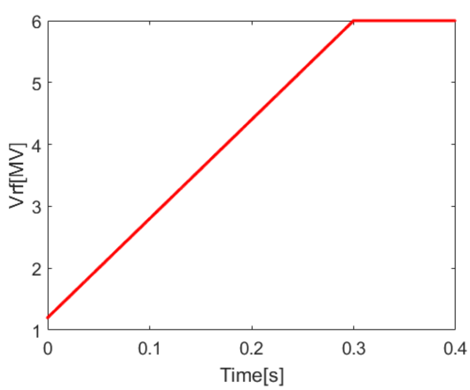

Figure 8: RF voltage during the energy ramp.

The bucket height and beam energy spread evolution in the ramping process with this RF voltage setting is presented in Figure 9. The bucket height is much larger than the beam energy spread, so that the energy spread of the accepted beam is limited by the physical aperture and/or the transverse off energy dynamic aperture of the lattice, not by the RF system.

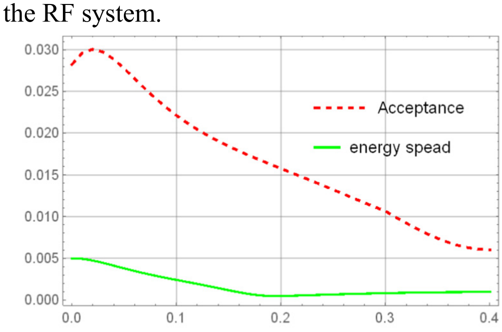

Figure 9: Bucket height and beam energy spread evolution during the energy ramp.

BOOSTER AS AN ACCUMULATION RING

When the storage ring operating in swap-out mode, the booster need provide about 14nC bunch charge. So, HEPS booster also need to have the ability of beam accumulation.

The accumulation process is realized with four steps, which is presented in Figure 10.

First, injecting the required charge to booster from linac, second, ramping up the booster energy to 6GeV, then the beam swapped out from storage ring is injected to the booster bucket with charge, after a few damping time, the accumulated beam with enough charge is extracted from booster and injected to storage ring.

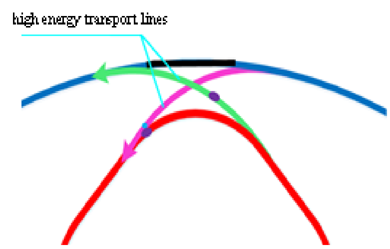

Figure10: The diagram of on-axis swap-out injection.

INJECTION AND EXTRACTION SYSTEM

The HEPS booster injection is a simple single turn on-orbit injection with the injection system consists of a lambertson and a kicker.

We choose vertical off-axis injection system as the extraction and reinjection scheme.

In the reinjection system, there are 2 kickers with phase advance π to generate a local orbit bump in the vertical plane and the beam will be deflected by a lambertson horizontally.

The extraction system consists of 4 slow bumper dipole, a kicker and a lambertson. The 4 slow bumper dipole are used to form an 8 mm bump for reducing the required strength of the kicker. The phase advance between the kicker and lambertson is π/2, making zero vertical angle at extraction point.

CONCLUSION

In this paper, we presented the lattice design, preliminary studies of ramping progress and so on. For meet the injection requirement, the booster is also used for beam accumulation. Reinjection system uses 2 kickers instead of 4 kickers to increase impedance.

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