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STUDY OF THE RAMPING PROCESS FOR HEPS BOOSTER*

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Abstract

The High Energy Photon Source (HEPS) is a 6-GeV, ultralow-emittance storage ring light source to be built in Huairou District, Beijing, China. The beam energy ramps from 500 MeV to 6 GeV in 400 ms, during which the RF voltage increases accordingly to keep the momentum acceptance large enough. The booster is designed to operate at 1 Hz repetition frequency. In this paper the energy ramping curve, RF choice, beam parameters changing curves and eddy current effect in HEPS booster will be presented.

INTRODUCTION

HEPS is a kilometre-scale, ultralow-emittance high energy storage ring light source to be built in Huairou District, Beijing, China.

The facility is comprised of a 6-GeV storage ring and a full energy injector. The lattice of HEPS storage ring is based on hybrid multi-bend achromatic (H-MBA) structure, adopting longitudinal gradient dipoles，anti-bend dipoles and combined magnets. The natural emittance is pushed down to about 34-pm.rad [1-3].

The dynamic aperture of the storage ring is only a few millimetres, leading to difficulties to accumulate charges if the traditional off-axis injection scheme is adopted. Thus, currently, the on-axis swap-out injection scheme [4] is chosen as the baseline. However, the swap-out injection scheme requires full-charge bunches from the injector, implying over 15 nC per bunch sometimes, which is a great challenge for the injector.

The 'high-energy accumulation' scheme [5] is therefore proposed to relax the requirements of single-bunch charge to the electron gun, linac, and the booster at the low energy. This scheme work with the bunches are extracted from the storage ring at an interval of about 20 ms, while a merged bunch stays in the booster for about 15 ms before being extracted and reinjected into the storage ring, as illustrated in Fig. 1.

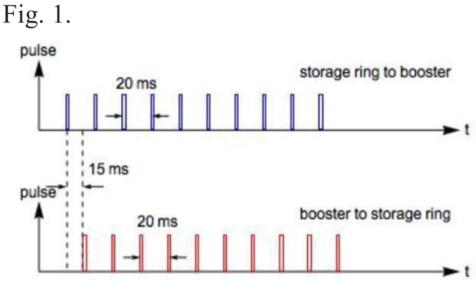

Figure 1: The time structure of bunches in two high energy transport lines.

In the preliminary design, we proposed to keep the capability of multi-bunch operation in the booster. The design of ramping curve therefore needs to take this requirement into consideration. Considering the engineering difficulties of the kickers, we current design the booster to have the 10-bunch operation capability. Since the repetition rate of all injection and extraction kickers is chosen as 50 Hz, the flat bottom and flat top of the ramping curve needs to be about 200 ms. The HEPS booster designed operated with 1Hz and the time of ramping 500-MeV up to 6 GeV is 400-ms.

LATTICE AND RAMPING CURVE

Lattice and Beam Parameters

The HEPS booster adopts a four-fold symmetric FODO lattice with single-function magnets. Each fold consists of 14 standard FODO cells and 2 matching cells.

The circumference of booster is changed to about 454.066 m which is designed for fit the timing requirements by the injection of the HEPS storage ring. There are 4 long dispersion-free straight sections for RF cavities, injection and extraction systems. The optical functions and lattice structure of quarter of the booster is shown in Fig. 2, and the main parameters used in this paper is listed in Ta-ble1.

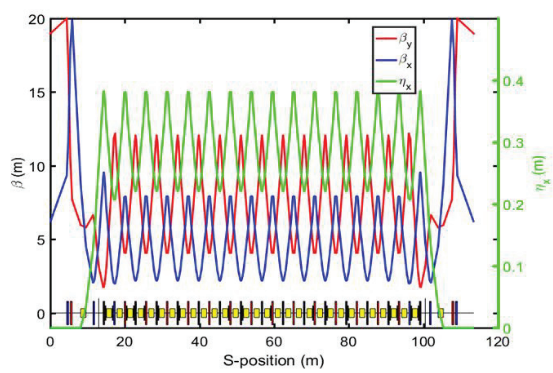

Figure 2: The optical functions and lattice structure of one quarter of the booster.

Table1：Main Parameters of HEPS Booster

Parameter	Value
Injection energy	0.5 GeV
Extraction energy	6 GeV
Circumference	454.066 m
Repetition rate	1 Hz
Emit. @0.5 GeV	41 nm.rad
Emit. @ 6 GeV	35 nm.rad
Tune(H/V)	17.21/11.15
Energy spread @ 6 GeV	9.6×10^{-4}
Natural chromaticity(H/V)	-18.5/-14.9
Momentum compaction factor	3.8×10^{-3}
Energy loss per turn @ 6 GeV	4.02 MeV
Damping time @ 6 GeV	4.5/4.5/2.3 ms

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Ramping Curve

The repetition rate of HEPS booster is 1-Hz. The electron gun and all injection and extraction kickers work at a 50 Hz repetition rate in HEPS, so the ramping curve is designed with 200 ms flat-bottom and a 200 ms flat-top to enable the transfer of up to 10 bunches between the booster and the storage ring in each ramping cycle.

For reducing the eddy current, the ramping curve was designed using the formula (1)

$$f(t) = \frac{1}{2}[1\text{-cos (w*t)}] \qquad (1)$$

The energy ramps up from 500 MeV up to 6 GeV in 400 ms and ramps down from 6-GeV to 500 MeV in 200- ms, the energy cycle of HEPS booster is shown in Fig. 3.

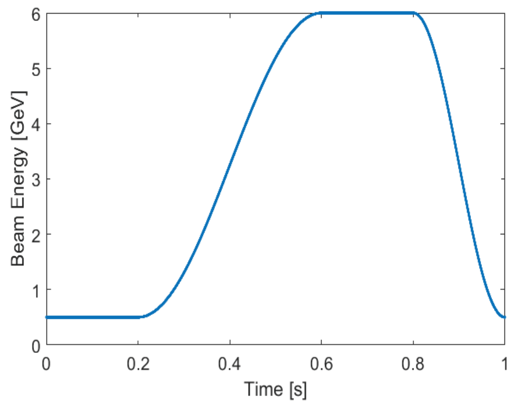

Figure 3: An energy ramp cycle of HEPS booster.

RF VOLTAGE

500 MHz PETRA-type 5-cell copper cavities are planned to be used in HEPS booster. For improving the threshold of transverse mode coupling instability (TMCI), the beam from linac is a 0.7 ns (FWHM) macro-pulse composed of three 5 ps (RMS bunch length) micro-pulses. Then, the voltage of RF cavity is designed as 2- MV at 500 MeV, and ramps linearly to 8 MV to make sure the longitudinal acceptance is big enough.

With the ramping of beam energy and RF voltage, the synchrotron phase is calculated as shown in Fig. 4 and the synchrotron tune is presented in Fig. 5. The synchrotron phase changes from 180 degree to 145 degree, and the synchrotron tune changes about 0.022.

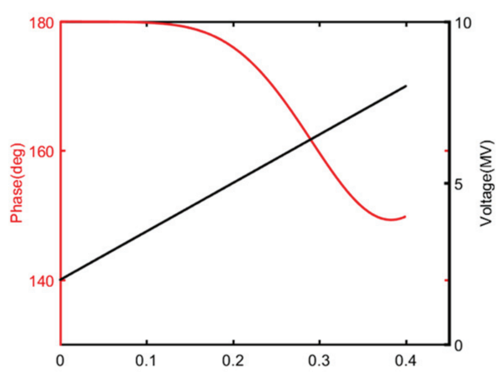

Figure 4: The synchrotron phase changes with RF voltage. Red line： synchrotron phase； Black line: RF voltage.

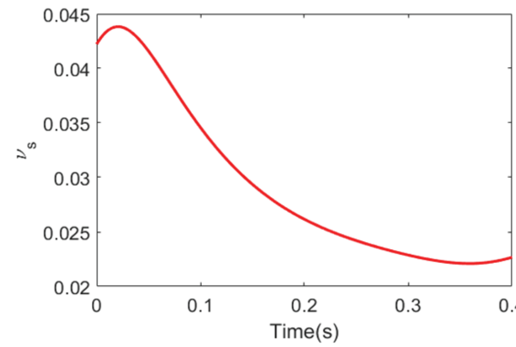

Figure 5: synchrotron tune curve in ramping process.

In the ramping up process, the bucket height is shown in Fig.6. The bucket height is about 3% at the injection energy and 1% (require by the high energy accumulation, the re-injection beam from storage ring energy spread can reach about 0.3% with impedance) at the extraction energy.

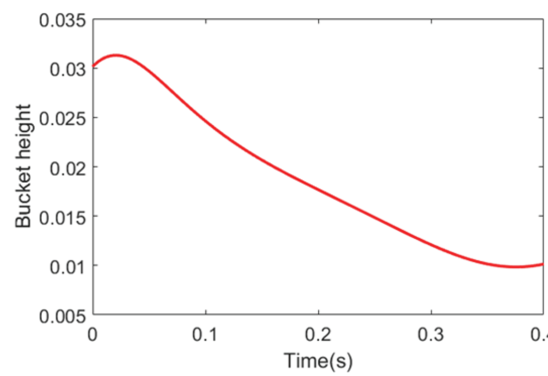

Figure 6: Bucket height changes in ramping up process.

EDDY CURRENT EFFECT

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, particularly an increased vertical chromaticity. To reduce the eddy current, 0.7 mm thick stainless steel is used for the vacuum chamber in HEPS booster, sextupole strength due to the eddy current is calculated with the formula given in ref. [6].

$$\mathrm{K}_2 = 2\,\mathrm{F}\,\mu_0\sigma\frac{h}{g}\frac{1}{B\,\rho}\frac{\partial B}{\partial t} \qquad (2)$$

Where F is given by

$$\mathrm{F} = 2\int_0^1[x^2 + \left(\frac{g}{w}\right)^2(1-x^2)]^{1/2}\mathrm{dx} \qquad (3)$$

The HEPS vacuum chamber with height 30 mm and width 36 mm. The induced sextupole strength is shown as a function of time, which is given in Fig. 7. The sextupole strength induced by eddy current reached largest value is about 0.062 m^{-3}.

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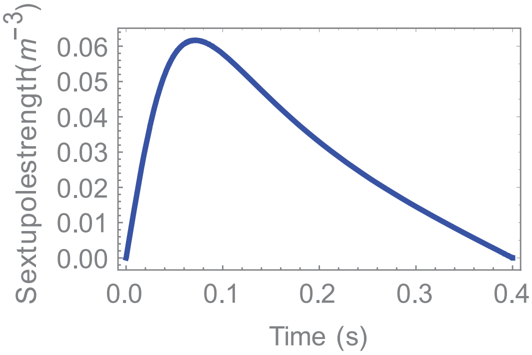

Figure 7: The sextupole strength induced by eddy current in ramping up process.

Figure 8 shows the total amount of chromaticity change due the eddy current. This chromaticity change can be corrected by varying magnetic field of sextupole magnet.

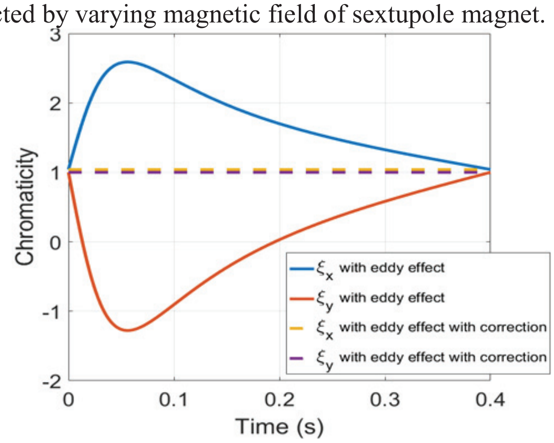

Figure 8: Eddy current induced chromaticity change.

Emittance and Energy Spread Evolution

Beam energy spread and emittance evolution with energy ramping can calculate by the following formula [7]

$$\frac{dA_i}{dt} = -A_i\left(\frac{\dot{E}}{E} + J_i\frac{P_\gamma}{E}\right) + C_q\frac{P_\gamma \gamma^2}{E}G_i \quad , \qquad (4)$$

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_γ is the synchrotron radiation power, $C_q=3.83*10^{-13}m$. $G_1=I_3/I_2$, $G_2=I_5/I_2$, I_2, I_3 and I_5 are the synchrotron radiation integration. The emittance and energy spread evolution are given in Fig. 9. The results showed that:

At low energies, the radiation damping effect is very weak, beam parameters are close to those of injected beam;

With the energy ramped up, stronger radiation damping make the beam parameters move to designed values. As the energy is larger than 3 GeV, the emittance and energy spread reach the balance between radiation damping and quantum exciting.

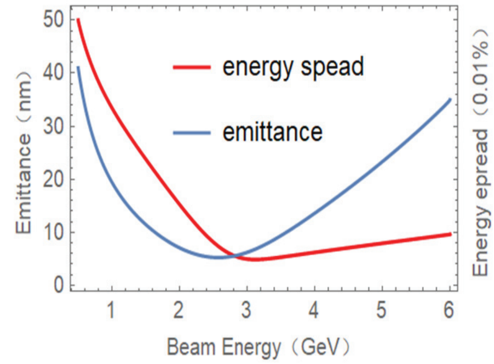

Figure 9: The emittance and energy spread evolution.

CONCLUSION

In this paper, the booster ramping cycle, RF voltage ramping scheme, eddy current effects and beam parameters change are presented. The repetition rate of HEPS booster is 1 Hz. The RF voltage ramps up from 2 MV to 8 MV linearly to get the longitudinal acceptance big enough. The voltage of RF cavity is designed 2 MV at 500 MeV linear ramping up to 8 MV at 6 GeV to get the longitudinal acceptance big enough. 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, and this change can be corrected by varying magnetic field of sextupole magnet.

REFERENCE

[1] Y. Jiao *et al.,* “Progress of lattice design and physics studies on the High Energy Photon Source”, *in Proc. 8st Int. Particle Accelerator Conf. (IPAC’18)*, Vancouver, Canada, Apr.-May 2018, pp.1375-1378.

[2] Y. Jiao *et al*., “Progress of lattice design and physics studies on the high energy photon source”, presented at IPAC’19, Melbourne, Australia, 2019, paper TUPGW046, this conference.

[3] G. Xu, Y. Jiao, Y. Peng, “ESRF-type lattice design and optimization for the High Energy Photon Source”, *Chin. Phys. C*, 40(2), 027001, 2016.

[4] Z. Duan *et al.,* “The on-axis swap-out injection scheme for HEPS”, presented in Proc. IPAC’18, Vancouver, Canada, Apr.-May 2018, paper THPMF052, pp.4178-4181.

[5] Y. M. Peng *et al.,* “Status of HEPS booster lattice design and physics studies”in *Proc. 8st Int. Particle Accelerator Conf. (IPAC’18)*, Vancouver, Canada, Apr.-May 2018, pp.1407-1410.

[6] Effects of Eddy Current Induced Sextupole Moments in the Booster during Ramping, CLS design note-3.2.69.2Rev.0, 2000.

[7] D. A. Edwards, M. J. Syfers, *An introduction to the Physics of High Energy Accelerators*, New York: John Wiley and Sons, Inc. 1993, p110-115.