CANDIDATE BOOSTER DESIGN FOR THE HEPS PROJECT*

Y.M. Peng†, Y. Jiao, G. Xu,Y.Y. Wei, Y.Y.Guo, Key Laboratory of Particle Acceleration Physics and Technology, Institute of High Energy Physics, Beijing 100049, China

Abstract

The High Energy Photon Source (HEPS), with transverse emittances of a few tens of pm.rad, is to be built in the suburbs of Beijing, China. The HEPS booster is a 2 Hz electron synchrotron. It accelerates electron bunches from a 300 MeV linac to a final energy of 6 GeV, and then extracts and injects them into the storage ring. We have made a candidate booster design, with a circumference of about 432 m and a natural emittance of about 4 nm.rad at 6GeV, which will be located in a separate tunnel. This lattice has a four-fold symmetry. Each super-period is composed of 13 identical cells and two matching cells. The lattice design and optimization and other considerations are presented in a detail.

INTRODUCTION

The High Energy Photon Source (HEPS), a 5 to 6 GeV synchrotron radiation facility with ultralow emittance, is to be built in the suburbs of Beijing, China. A preliminary storage ring design, with a circumference of about 1296 m and a natural emittance of about 60 pm.rad at 6 GeV, was developed [1] based on the 'hybrid MBA' concept [2]. More recently the nonlinear performance of this design was improved [3] by means of sextupole strength minimization and tune space survey. More details of this design and related studies are shown in Ref. [4].

For HEPS, we planned to use a 300 MeV linac and a 2 Hz synchrotron to provide 6-GeV, low-emittance electron bunches for injection into the ring. Since the HEPS project is still under design. We are simultaneously exploring booster designs of two options. One option is to locate the booster in the same tunnel as the ring, and the other option is locate the booster in a separate tunnel with smaller circumference.

In this paper, we will show in detail the booster design in a separate tunnel, including the lattice design, optimization and other related studies.

PHYSICS DESIGN

Booster Lattice Description

The separate-tunnel booster design has a four-fold symmetric geometry. Each super-period is composed of 13 modified theoretical minimum emittance (TME) cells with gradient dipoles [5] and two matching cells. This design provides four dispersion-free 10-m long straight sections to accommodate RF cavities, injection and extraction system. The circumference was chosen to be about 432m, 1/3 of the circumference of the ring, for a convenient timing design. The layouts of a modified TME cell and the matching cell with the long straight section are shown in Figs. 1 and 2, respectively. The optical functions along half a super-period are shown in Fig. 3. The main parameters of the booster are listed in Table 1.

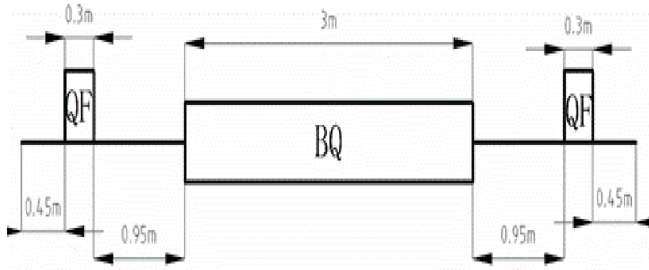

Figure 1: The layout of an identical cell.

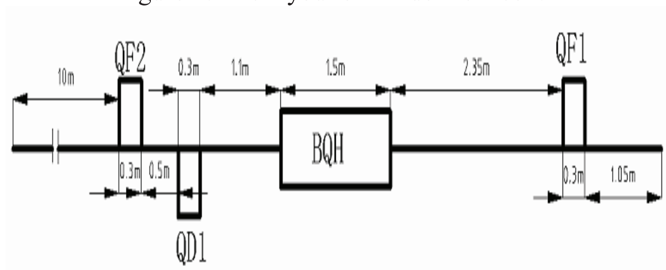

Figure 2: The layout of the matching cell with the long straight section.

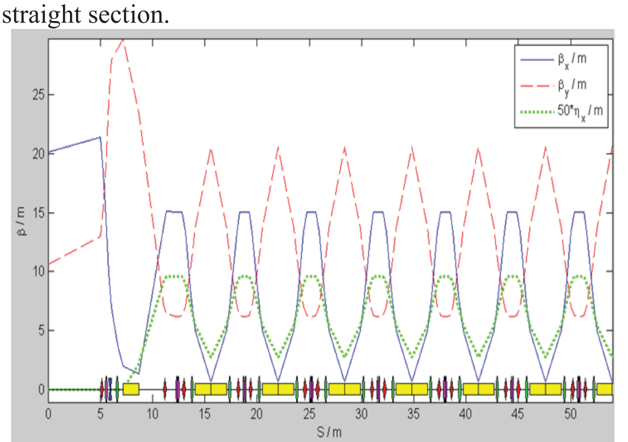

Figure 3: Optical functions along half a super-period.

Nonlinear Optimization

Two families of sextupoles distributed in each unit cells were used for chromaticity correction. In addition, we used additionally three families of harmonic sextupoles in the dispersion-free straight sections to minimize the nonlinear driving terms.

The set of sextupole strengths was optimized, and the dynamic aperture (DA) and the frequency map (FM) are calculated with the AT program, as shown in Figs. 4 and 5. It appears that the DA is larger than 17.5 mm for momentum deviations of less than 1.5%. The tune footprint is clear of dangerous resonances.

* supported by NSFC (11475202, 11405187,1150519)
† pengym@ihep.ac.cn

ISBN 978-3-95450-147-2

Table 1: Main Parameters of the Booster Design

Parameters	Values
Injection Energy	0.3 GeV
Extraction Energy	6 GeV
Circumference	432 m
Straight section length	10 m
Emittances (H/V) at 0.3GeV	70/70 nm.mrad
Natural emittance at 6GeV	4 nm.rad
Harmonic number	720
RF frequency	500 MHz
Maximal beta function (H/V)	21.4/29.8 m
Maximal dispersion	0.191 m
Horizontal tune	25.14
Vertical tune	6.22
Natural chromaticity (H/V)	-51/-22
No. of super-periods	4
Energy loss per turn at 6GeV	4.29 MeV
RMS energy spread at 6GeV	1.2×10^{-3}
Momentum compaction	9.86×10^{-4}
Damping time at 6 GeV	2.47/ 4.02/ 2.93 ms
Ramping repetition rate	2 Hz

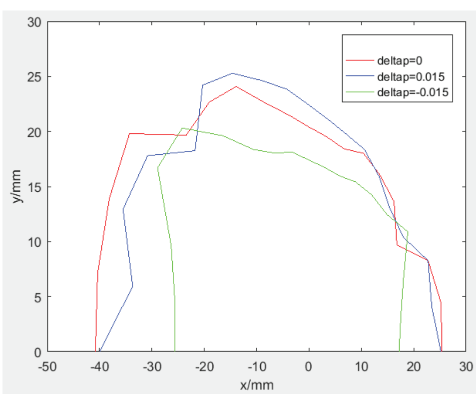

Figure 4: DAs with different momentum deviations.

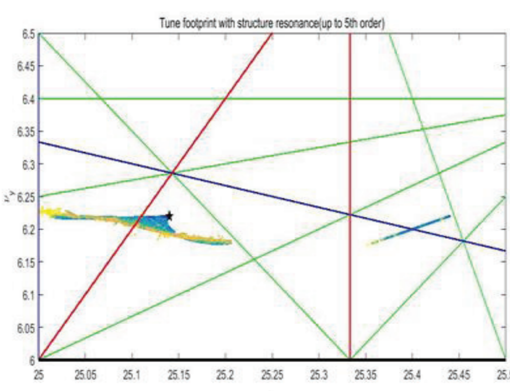

Figure 5: The frequency map of the booster lattice for on-momentum particles.

Magnet Apertures

It has been assumed that at injection into the booster horizontal and vertical emittance of the beam from the linac is 70 nm.mrad, the energy spread is assumed to be 0.15%. With these assumptions and the optical functions, the transverse beam sizes were calculated and shown in Fig. 6. The maximum beam size is 1.2 mm horizontally and 1.4 mm vertically.

It is assumed that the magnet aperture should not be less than 20 times of the beam sizes. Table 2 lists the main parameters for dipoles, quadrupoles and sextupoles.

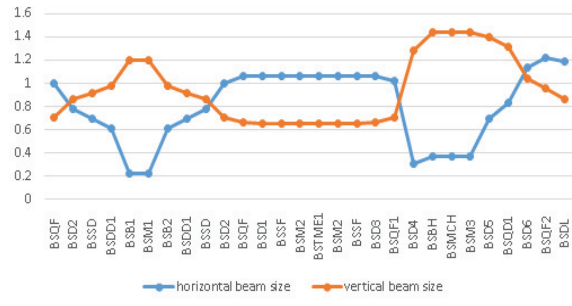

Figure 6: Electron beam size (in unit of mm) in a TME and a matching cell.

Table 2: Magnet Parameters of the HEPS Booster

Parameters	Values
Bending magnet（identical/half length）	
Number	52/8
Peak dipole field	0.9 T
Length	3/1.5 m
Max. gradient	4 T/m
Gap height	25/30 mm
Quadrupoles	
Number	128
Length	0.3 m
Aperture radius	13 mm
Max. gradient	35 T/m
Sextupoles (SF/SD/SH)	
Number	56/104/16
Length	0.3/0.2/0.2 m
Aperture radius	15 mm
Max. gradient	600 T/m^2

RF System

The required accelerating voltage for a booster synchrotron is largely dependent on the required quantum lifetime and energy acceptance.

For 500 MHz cavities, RF voltage should be at least 5.2 MV, which corresponds to a quantum lifetime of about 448 s, bunch length of about 11mm and the bucket height of about 0.8% at 6GeV. At injection energy this voltage can provide a much larger bucket height.

LATTICE DESIGN OPTIMIZATION

The goal of the optimization is to reduce the cost, while without degradation in the performance. Namely, we tried to use as small number of magnets to realize similar emittance and satisfying performance.

From a simple test, we found that it is feasible to use two families of quadrupoles in the dispersion-free straight section for optics matching and use only the chromatic sextupoles for nonlinear optimization.

It has been demonstrated [6] that a rational combination of MOPSO and MOGA would be more effective in a multi-objective optimization than using either of these two algorithms. Thus, we first used MOPSO and MOGA methods to optimize the emittance and chromatic sextupole strengths, where all possibly tuneable element parameters were varied, and only two families of chromatic sextupoles were used. For the optimized solutions, we calculated the corresponding DA. The results are shown in Fig. 7. It appears feasible to achieve emittance as low as 3.6 nm.rad with the 15BA lattice structure. However, for the cases with emittance below 3.8 nm.rad, one can see an obvious DA reduction in both x and y planes. Moreover, even with larger emittance, if with only two families of sextupoles, it is not possible to achieve DA of about 20 mm. Further study showed that the DA depends on both parameters (see Fig. 8).

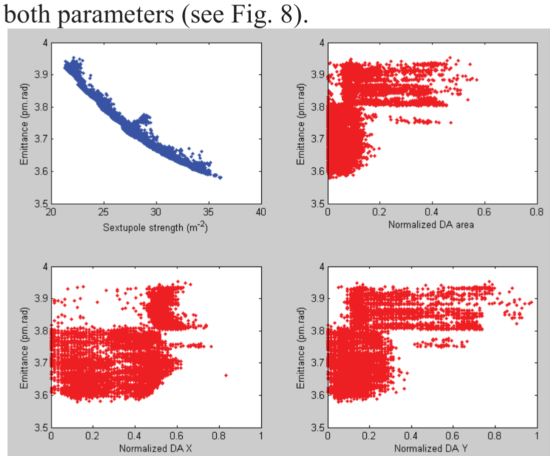

Figure 7: Optimized solutions obtained with MOPSO and MOGA algorithms and the corresponding DA sizes (normalized with respect to 20 mm) in x and y planes.

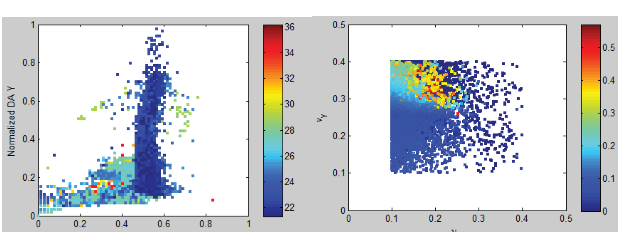

Figure 8: Relations between the DA size and sextupole strengths (left) and relations between the DA size and tunes.

To look for designs with DA of around or close to 20 mm (of the order of magnet aperture), we split the chromatic sextupoles in five families according to the phase advances between the sextupoles. And then we implemented successive MOPSO and MOGA optimizations, where the horizontal and vertical DA sizes were used as optimizing objectives. The emittance is used as a constraint. If the resulting emittance is larger than 4 nm.rad, the two objectives will be multiplied by a factor small than 1. The evolution of the population is shown in Fig. 9. From the final population, we kept those with objective functions of larger than 0.8, used them for post analysis. It was found that most solutions have emittances of above 4 nm.rad. The solutions distribute in three separate integer tune regions (see Fig. 10). From these solutions, candidate designs with emittances of about 4.3 nm.rad and DA larger than 20 mm in both x and y planes were found (due to limited space, the results are not shown here).

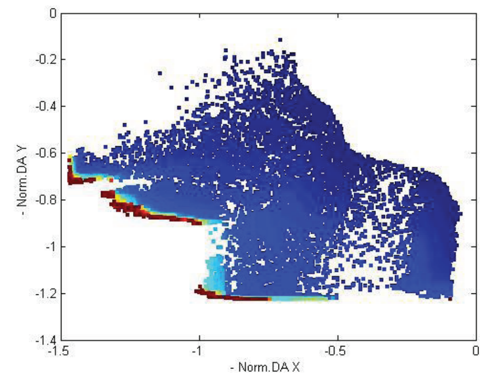

Figure 9: Optimized solutions obtained with MOPSO and MOGA. Different colors represent different generation of the population evolution.

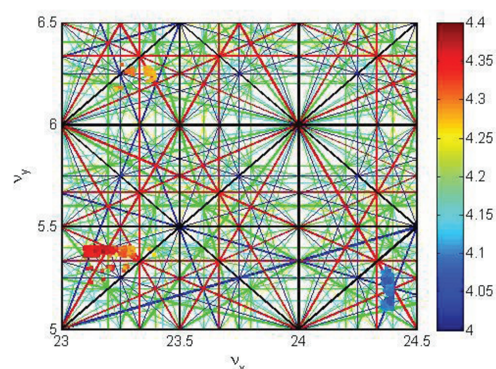

Figure 10: Solutions in the tune space, with the colors representing the emittance.

REFERENCES

[1] G. Xu, Y. Jiao, and Y. Peng, *Chin. Phys. C*, 40 (2): 027001.

[2] L. Farvacque *et al.*, in *Proc. IPAC'13*, pp. 79-81.

[3] Y. Jiao, *Chin. Phys. C*, 40 (7): 077002.

[4] G. Xu *et al.*, "Recent physical studies for the HEPS project", presented at *IPAC'16*, Busan, Korea, May 2016, WEPOW026.

[5] Y. Jiao, Y. Cai, A.W. Chao, *Phys. Rev. ST Accel. Beams*, 14: 054002(2011)

[6] Y. Jiao and G. Xu, "Comparing the performance of MOGA and MOPSO in optimization of the HEPS performance", presented at *IPAC'16*, Busan, Korea, May 2016, HPMB019.

ISBN 978-3-95450-147-2