LATTICE DESIGN OF LOW BETA FUNCTION AT INTERACTION POINT FOR TTX COMPACT RING *

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Abstract

A storage ring is being designed at Accelerator Laboratory in Tsinghua University to increase the average photon flux generated by Tsinghua Thomson scattering x-ray source (TTX). To achieve a small beta function at the interaction point(IP), four pairs of quadrupole magnets are added to the baseline design. Global scan of all stable settings and genetic algorithm(GA) techniques are utilized to optimize the design. The lattice design is presented in this work.

INTRODUCTION

The number of scattered photons in single collision is proportional to the luminosity and the total cross section of Thomson scattering. [1]

$$n_\gamma = L\sigma \tag{1}$$

In laboratory frame, the luminosity can be described by Eq. 2. [1]

$$L = \frac{n_e n_l}{2\pi\sqrt{\sigma_{ye}^2+\sigma_{yl}^2}\sqrt{\sigma_{xe}^2+\sigma_{xl}^2+(\sigma_{se}^2+\sigma_{sl}^2)\tan^2(\varphi/2)}} \tag{2}$$

where $\sigma_{x,y,se}$ and $\sigma_{x,y,sl}$ denote the horizontal, vertical and longitudinal sizes of electron and laser beams at interaction point, respectively. The collision plane is assumed to be horizontal. φ is the collision angle.

The transverse electron beams sizes are determined by beta functions and dispersion functions at IP.

$$\sigma_{xe} = \sqrt{\epsilon_x\beta_x + \eta_x^2\delta_p^2} \tag{3}$$

$$\sigma_{ye} = \sqrt{\epsilon_y\beta_y} \tag{4}$$

where ϵ_x and ϵ_y are the horizontal and vertical emittances. δ_p is the momentum spread of the electron beam. η_x is the dispersion function at IP. β_x and β_y are the horizontal and vertical beta functions.

In order to increase the number of photons scattered, the IP should be dispersion free and the beta functions should be small. The baseline lattice consists of four dipoles and two vertically focusing quadrupoles. The layout of the baseline lattice is shown in FIG. 1. [2]

Figure 2 shows the optics functions of the baseline lattice. The IP is located at the ring start. As shown in the figure, the horizontal beta function at IP is larger than 1m and the dispersion function is around 0. To lower the betatron functions at IP, a mini-beta lattice is designed on the basis of the baseline lattice.

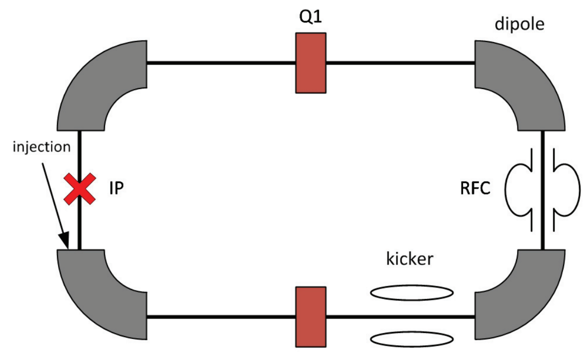

Figure 1: Layout of the baseline lattice.

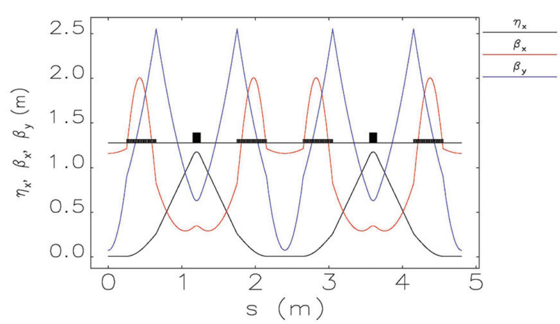

Figure 2: The optics functions of the baseline lattice.

MINI-BETA LATTICE

To lower the betatron functions at IP, doublets are added to the straight section where the IP is located. The addition of extra quadrupoles reduces the super-period to one, and increases the tunes of betatron oscillation, from below 1.5 to above 1.5. To ensure a large enough dynamic aperture, the operating point should be far enough from major low-order resonances. Thus two more pairs of quadrupoles are placed in the straight sections between the dipoles and the existing quadrupoles, to help adjust the betatron tunes. The layout of the mini-beta lattice is shown in FIG. 3.

Global scan all stable setting and genetic algorithm techniques are exploited to search for potential mini-beta lattice configurations. The program MAD-X developed by CERN

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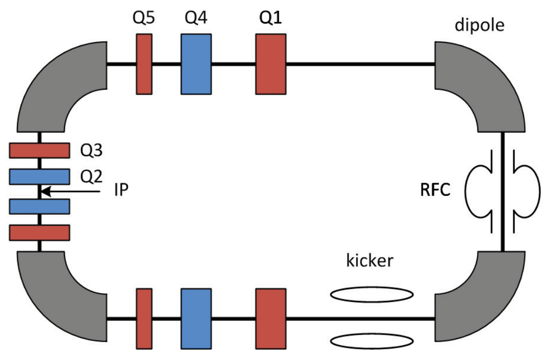

Figure 3: Layout of the mini-beta lattice.

is used in the global scan. [3] We first scan all possible settings of quadrupole strengths to find all stable ones. Then the properties of the stable settings such as betatron tunes, beta functions at IP, natural chromaticities are computed, and the scan results are filtered by these properties so that only those of interest are left.

The global scan technique is only feasible when the number of variables is small and the step sizes of variables are large, as the computing time exponentially depends on them. To address this limitation and for further optimization, genetic algorithm technique is exploited. First, we take the scan results as inputs to GA. Then a population of possible settings around input are created and evolved by mimicking natural evolution process such as mutation, crossover and selection. With the global scan results, we can get a rough idea of what we can achieve with the current lattice layout. The objective of GA is a function of lattice properties such as betatron tunes, beta functions and dispersion function at IP, natural chromaticities and momentum compaction factor. The target values of these properties are chosen such that they are not too far from scan results. The program ELEGANT is used in this optimization process. [4]

Figure 4 shows the optics functions of the current mini-beta lattice. The horizontal beta function at IP is around 0.2m and the dispersion function is around 0. Table 1 summarizes the beam parameters of baseline and mini-beta lattice.

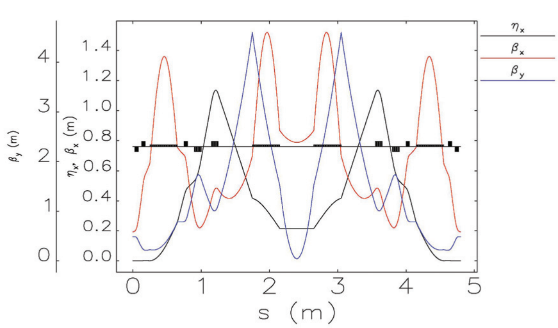

Figure 4: The optics functions of the mini-beta lattice.

The optimization is still under way. The horizontal beta function at IP will be reduced by a few more factors after completion.

Table 1: Beam Parameters of Baseline and Mini-beta Lattice, * Indicates IP

Beam Parameter	Baseline	Mini-beta
Beta functions (β_x^* / β_y^*)	1.16 / 0.0756	0.194 / 0.489
Dispersion function (η_x^*)	8.17e-3	1.00e-3
Betatron tunes (ν_x / ν_y)	1.21 / 1.28	1.40 / 1.40
Chromaticities (ξ_x / ξ_y)	-2.10 / -0.989	-1.1 / -1.1
Momentum compaction factor (α_c)	0.133	0.280
Damping partition number (J_x)	1.108	0.999

DYNAMIC APERTURE

Dynamic aperture is evaluated at IP by tracking simulation using the program ELEGANT. Figure 5 plots the dynamic aperture, including on-momentum and off-momentum particles. Since natural chromaticities in both horizontal and vertical planes are small, we decide not to correct the chromaticities. The tune shift with different momentum deviance is listed in Table 2. As shown in Table 2, tune shift due to momentum deviance is small.

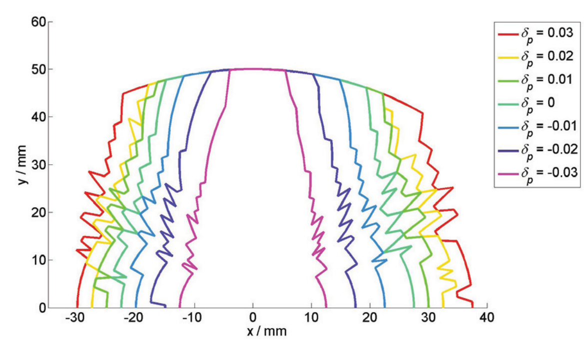

Figure 5: The dynamic aperture of the mini-beta lattice.

Table 2: Tune Shift with Different Momentum Deviation

δ_p	ν_x	ν_y
0.03	1.3737	1.3711
0.02	1.3811	1.3800
0.01	1.3898	1.3896
0	1.4000	1.4000
-0.01	1.4119	1.4117
-0.02	1.4253	1.4254
-0.03	1.4395	1.4425

The equilibrium emittances are expected to be not so different from those of the baseline lattice. Thus the equilibrium emittances of the baseline lattice are used to estimate

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the transverse beam sizes at IP. In regard to the baseline design, the horizontal and vertical equilibrium emittances are 3.15 μm and 0.285 μm, respectively. Substitute these values into Eq. 3 and Eq. 4, and we can get the transverse beam sizes, which are 0.782 mm and 0.373 mm. [2] Therefore the dynamic aperture should be large enough for a long beam lifetime.

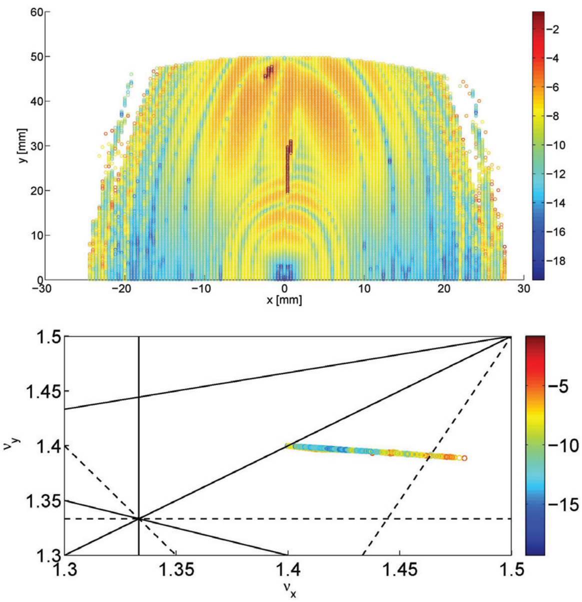

Figure 6: The dynamic aperture and frequency map with diffusion rate of on-momentum particles.

Figure 6 shows the on-momentum particle dynamic aperture and its frequency map at interaction point with tune diffusion rate. The diffusion rate is indicated by color, whose definition is described by Eq. 5.The lower the diffusion rate, the more stable the particle. As seen in Fig. 6, the diffusion rates of most particles and tune spread are small, which indicates most particles are stable.

$$d = \log_{10}(\Delta\nu_x^2 + \Delta\nu_y^2) \quad (5)$$

CONCLUSION

The lattice design for low beta function at interaction point for Tsinghua Thomson scattering x-ray source is presented. Doublets of quadrupole magnets are placed in the straight section where the IP is located to lower the betatron functions at IP. Two pairs of quadrupole magnets are added to help adjust operating point. The horizontal beta function is reduced from 1.15m to less than 0.2m. Thus an average increase in photon flux by a factor of two can be expected in the mini-beta lattice, depending on RF voltage and beam current. The photon flux increase is confirmed by simulation with CAIN. [5] The horizontal dynamic aperture reaches 10mm for momentum spread between -3% and 3%, and thus a long beam lifetime can be expected.

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