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LATTICE DESIGN FOR A 1.2 GeV STORAGE RING

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Abstract

It is an effective way to bring down the emittance of storage ring by using the longitudinal gradient magnet lattice design. In this paper, we will present the lattice design for a 1.2 GeV storage ring. The solution of horizontal and longitudinal gradient bending magnets tried in this lattice is going to be discussed in detailed.

INTRODUCTION

This paper will bring lattice design for a 1.2 GeV storage ring which can be used for universities [1] and enterprises [2]. The low energy storage ring, as a synchrotron radiation source, has unique advantages in the production of soft X ray and vacuum ultraviolet radiation with its small scale, low cost and weak radiation heat load [3]. It is very helpful for other science research as vacuum ultraviolet and infra-red can be used for microscopic imaging. Several methods have been taken to reduce the emittance and it proved to be effective in some conditions.

Horizontal gradient dipole on the base of bare lattice will be introduced at first. This method increase the number of horizontal damping partition number which can affect the emittance directly and effectively.

Further, much time spent on the lattice with longitudinal gradient dipole. It is much more complicated than the horizontal one as the integrals of function H is closely related to the twiss parameters which is hard to control in the lattice.

SOLUTIONS TO REDUCE THE EMITTANCE

The natural horizontal emittance εx can be expressed as

$$\varepsilon_x = C_q \frac{\gamma^2}{J_x} \frac{\oint (H/\rho^3) ds}{\oint ds/\rho^2} = C_q \frac{\gamma^2}{J_x} \frac{I_5}{I_2}, \tag{1}$$

where $C_q = 3.83\times10^{-13}$ m, γ is the relative energy, J_x is the horizontal damping partition number, γ is the local bending radius at position s,

$$H(s) = \gamma_x \eta_x^2 + 2\alpha_x \eta_x \eta_x' + \beta_x \eta_x'^2, \tag{2}$$

where α_x, β_x, γ_x are the horizontal Courant–Snyder parameters and η_x, η_x' is the dispersion and its derivative. The TME with dispersion-free optics is well known as:

$$\varepsilon_{x\min} = \frac{C_q \gamma^2 \theta_0^3}{4\sqrt{15} J_x}, \tag{3}$$

while TME with dispersion optics is well known as:

$$\varepsilon_{x\min} = \frac{C_q \gamma^2 \theta_0^3}{12\sqrt{15} J_x}, \tag{4}$$

where θ_0 is the bending angle per dipole.

Emittance can be reduced by changing the value of I_5/I_2 and J_x. It is a simple way to bring down the emittance by increasing the number of bending magnets, achromat cells or dipoles in one cell. This solution decreases the bending angle per dipole θ_0 which makes it very effective. However, it is based on the existing light sources in most cases, also limited by the magnet technology and budget. Some other solutions like longitudinal gradient dipole can decrease I_5/I_2 while horizontal gradient dipole and robinson wiggler can increase damping partition number J_x.

FOUR TYPES OF LATTICE

The Bare Lattice

The lattice of the 1.2 GeV storage ring consists of 6 cells and each cell has four dipoles, six or ten quadrupoles. Circumference of the ring is 96 m. The whole ring can be seen as Fig. 1 and the lattice of one cell is shown in Fig. 2.

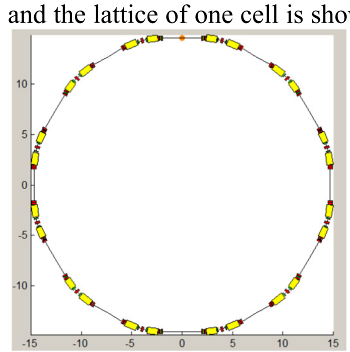

Figure 1: Lattice of the 1.2 GeV storage ring.

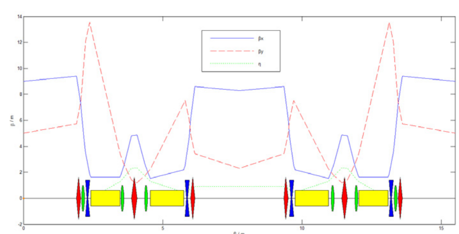

Figure 2: Linear optics in one cell of the bare lattice.

The bare lattice has four dipoles, ten quadrupoles, dispersion-free at both ends and dispersion in the middle straight section. Two dipoles, whose length is 1.05 m, are dispersion-free at the place of start and end in this cell. The other two dipoles, whose length is 1.2 m, have dispersion in the middle of the cell.

We use the method of MOGA [4] to explore a more optimal optics which gets lower emittance by adjusting the tune and Twiss function. It can help us find the range of the relative best optics for four types of lattices in this paper and we will do some adjustments based on it.

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With the adjustment of tunes and βx at the entrance of dipole, we can get the smallest emittance for the bare lattice. βx at the entrance and middle place of dipole is relatively high and hard to bring down which is the main cause of integral of function H too big. The smallest emittance is 4.964×10^{-4} when we balance the βx well at the tunes of 11.22/4.21.

For this type lattice, the TME should be 1.5 nm·rad as calculated. We will reduce the emittance as far as possible within the aim of 1.5 nm·rad.

In the next steps, the whole structure unchanged, including the circumference, beam energy, RF voltage, even the length of short and long straight knot. Meanwhile, we try to keep the tunes and βx at the entrance about the same with bare lattice which make the comparison fairer. The gradient of dipole is the main character with big change in this paper and the unchanged things will not be repeated below.

The Lattice with Horizontal Gradient Dipole

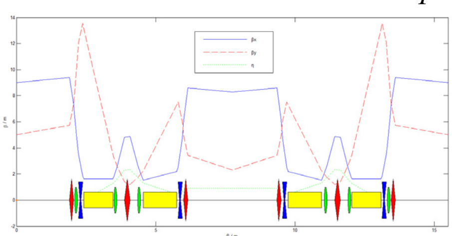

Figure 3: Linear optics in the lattice with horizontal gradient dipole.

In the lattice with horizontal gradient dipole, which can be seen in Fig. 3, the horizontal gradient has taken the place of the original four defocus quadrupoles. The horizontal gradient is -1.2292, which changes the horizontal damping partition number from 1.0058 to 1.6057. The emittance also reduced down to 2.98 nm·rad. With the horizontal gradient dipole, we can increase the horizontal damping partition and reduce the emittance easily. We get the smallest emittance at the tunes of 11.22/4.21.

The Lattice with Longitudinal Gradient Dipole

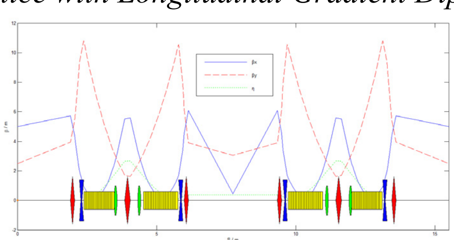

Figure 4: Linear optics in the lattice with longitudinal gradient dipole.

The lattice with longitudinal gradient dipole can be seen in Fig. 4. As anticipated, the lattice with longitudinal gradient dipole will have an effect of reducing the integrals of function H if $\rho^{-1}(s)$ rapidly decays when η and η' grow large [5]. We choose the decay to be exponential

$$\frac{1}{\rho(s)}=\frac{\mu}{\rho_0}\frac{1}{\left(1-e^{-\mu}\right)}e^{-\lambda s}. \qquad (5)$$

To achieve the effect of longitudinal gradient, we need to cut the dipole into slices when simulating in the Matlab program. Before we determine the gradient λ, the number of slices should be chosen. In the progress of simulation, we use a fixed gradient and keep the tunes(11.35, 4.14) and βx(5,2.5) at the entrance unchanged. Then we get a trend of emittance decreasing with slices growing more, which can be seen in Fig. 5. At last, we divide the dipole into twenty slices, as more slices will get lower emittance but the change will be quite small when the slices are over ten. It is steady when slices are twenty and it leave us space to do some tiny changes at the end of dipoles which may help decrease the emittance furthermore.

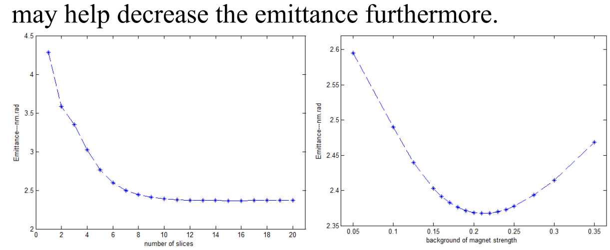

Figure 5: Smaller emittance with more slices (left); Emittance change with different background of magnet strength(right).

We also need to give the magnitude a suitable background otherwise the magnet cannot be made out. Eq. (5) will change into Eq. (6):

$$\frac{1}{\rho(s)}=\frac{\mu}{\rho_0}\frac{1}{\left(1-e^{-\mu}\right)}e^{-\lambda s}+\text{bg}, \qquad (6)$$

where bg is the value of background. When the gradient λ remains unchanged, the emittance will change with the background, which is showed in Fig. 6. The background cannot be too large or too small which will affect the emittance. Actually, we can find that the relationship between emittance and background of magnet strength is caused by the change of quotient. So, keep the gradient λ and change the quotient, we can get a similar figure. Conversely, keep the quotient unchanged as 5 and search for a suitable gradient λ, we can get Fig. 6.

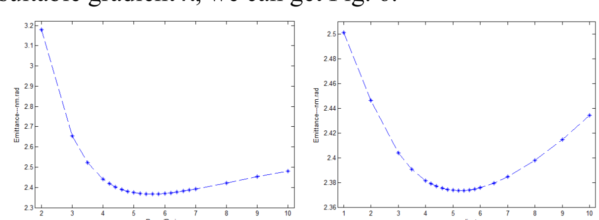

Figure 6: Emittance change with different quotient (left); Emittance change with different gradient (right).

From two figures above, we know that the emittance will change with the quotient and the gradient. Every different variable can get a minimal emittance by changing another variable. While the minimum emittance got when quotient unchanged is the same as the one got when gradient unchanged. So what we need to do is just to find the minimal emittance in the minimal emittances for one different variable. Finally, we get the magnet strength of dipoles for minimum emittance as follow figures when

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the quotient and the gradient are both 5. The gradient of the dipole is shown as Fig. 7.

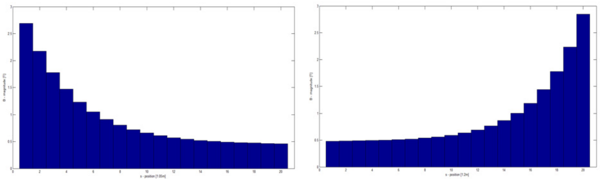

Figure 7: The gradient of the dipole in longitudinal direction (left is the 1.05 m dispersion-free dipole, right is the 1.2 m dispersion dipole).

The emittance of this lattice will reduce down to 2.37 nm·rad at tunes of 13.35/4.14. As we can see on Fig. 6, the magnitude of dipole grows very large at the edge where η and η' is very small. It is difficult to find the most suitable lattice for small emittance tunes of 11.22/4.21.

The Combined Function Gradient Dipole

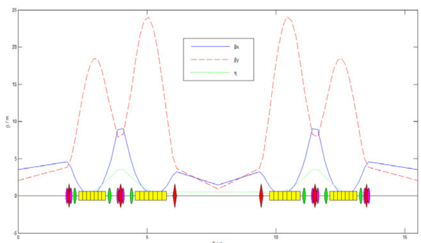

Figure 8: Linear optics in the lattice with horizontal and longitudinal gradient dipole.

The combined function gradient dipole is shown in Fig. 8. We divided the dipoles into only seven slices as the combined function dipole is hard to achieve. The horizontal gradient is -1.2579, which changes the horizontal damping partition number from 1.0058 to 1.3748. The emittance reduced down to 2.38 nm·rad which did not reach our expectation.

Comparisons

As we can see, the gradient in the horizontal direction can increase the horizontal damping number and gradient in the longitudinal direction decrease the integrals of function H. These two methods can help us on reducing the emittance.

Table 1 is charted and Fig. 9 is plotted to help comparing the emittance reduction efficiency of these four lattices. The lattice with longitudinal gradient dipole has been the most effective method which reduces emittance by 40% compared to the original lattice. We can only reduce the emittance down to the same level with longitudinal method by using the combined function dipole in this lattice.

Table 1: The Main Parameters of Four Lattices

Parameter / unit	original	horizontal	longitudinal	combined
Natural emittance / nm·rad	4.04	2.98	2.37	2.38
Horizontal damping number	1.0058	1.6057	1.0023	1.3748
Momentum-compaction number	3.52×10^{-4}	3.62×10^{-4}	2.66×10^{-3}	3.23×10^{-3}
Natural chromaticity	-39.2, -4.3	-24.68, -24.43	-27.06, -17.65	13.77, 9.25
Tune (H, V)	11.22, 4.21	11.22, 4.21	13.35, 4.14	12.35, 4.14
Natural energy spread	4.9646×10^{-4}	5.9373×10^{-4}	6.9939×10^{-4}	7.3857×10^{-4}

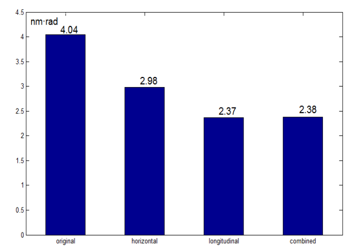

Figure 9: The emittance of four lattices.

CONCLUSION

We proved that longitudinal gradient dipole is an effective way to bring down the emittance. There is also some space to reduce the emittance such as better matching and little changes in longitudinal gradient magnets which will be studied in next period. While it seems that the combined function magnets doesn't work for the emittance further more in this lattice. But we still need to try it for other storage ring lattice.

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