DESIGN AND STUDY OF A TCF LATTICE WITH NEGATIVE MOMENTUM COMPACTION FACTOR

J.Q. Wang and S.X. Fang
IHEP, Chinese Academy of Sciences, P.O. Box 918(9), Beijing 100039, P. R. China

Abstract

The feasibility of designing a negative momentum compaction factor ($\alpha_p < 0$) lattice for a circular $e^- e^+$ collider is investigated. The modular method for an $\alpha_p < 0$ lattice is introduced. As a practical example, an $\alpha_p < 0$ lattice for a Tau-charm factory(TCF) is proposed and studied.

1 INTRODUCTION

The new generation of circular $e^- e^+$ colliders called "factories" are aiming at luminosities two orders of magnitude higher than existing machines. By study of the luminosity related formulas, the ingredients for high luminosity can be defined [1]:

- Very low beta functions at the interaction point, adopting mini-β^* or micro-β^* schemes.
- Increase of the number of particles per bunch following an increase in emittance.
- Increase in the total circulating current by having more bunches per beam.

The two rings configuration is being adopted in the present design of $e^- e^+$ factories and the bunch number can be very large, so the key points to realize high luminosity concentrate on the first two items of the above.

Experimentially, a enough small bunch length is required for high luminosity when β^* is at a low value, i.e. $\sigma_z \leq \beta^*$ should be kept, where σ_z is the rms bunch length. Usually, a small $|\alpha_p|$ is chosen in order to obtain the short bunch length. In a normal $\alpha_p > 0$ lattice, there is relation:

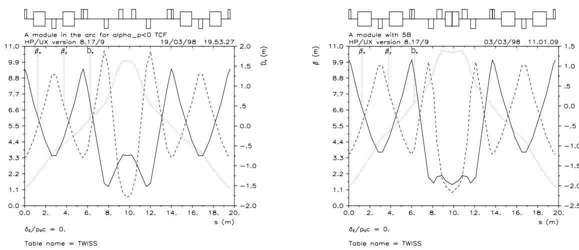
$$\epsilon_x \propto \frac{1}{{\nu_x}^3} \quad , \quad \alpha_p \propto \frac{1}{{\nu_x}^2} \tag{1}$$

where, ϵ_x is the horizontal emittance and ν_x the betatron oscillation tune. As a result, it is difficult to satisfy both the small α_p and large ϵ_x simultaneously. But when the negative dispersion is introduced, the above relation (1) breaks. We can design an $\alpha_p < 0$ lattice in the case dispersion function $D_x < 0$ in some bending magnets and $D_x > 0$ in other bending magnets, but $|D_x|$ being large. The positive dispersion may partially cancel the negative one, then $|\alpha_p|$ will be small. But ϵ_x is proportional to $|D_x|$, it can be large. Thus, small $|\alpha_p|$ and large ϵ_x can be got in an $\alpha_p < 0$ lattice, that will benefit high luminosity.

It has been pointed out that bunch lengthening is much weaker in an $\alpha_p < 0$ storage ring[2]. So far, we can deduce that with an $\alpha_p < 0$ lattice, it's possible to store large current in a short bunch, that is helpful to high luminosity. As a practical example, an $\alpha_p < 0$ lattice for a TCF is proposed and studied[3].

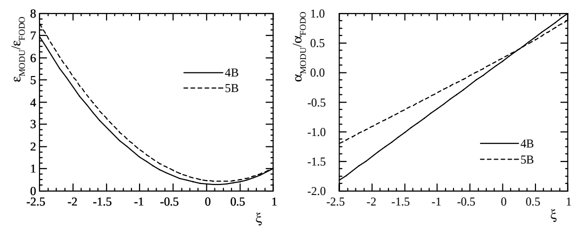
2 MODULAR METHOD FOR $\alpha_P < 0$ LATTICE

The $\alpha_p < 0$ lattice was initially developed for the transitionless scheme in proton machines[4]. A modular method has been proposed by S.Y. Lee et al[5]. We follow the idea. But in contrast to keeping the dispersion action small in a proton machine, we have to match the D_x to a large negative value for the fairly large emittance needed in a TCF. A basic module composed of two parts: 1) The FODO cell part where the dispersion in the dipoles is matched to negative so as to provide a negative α_p, and 2) a matching section which matches the optical functions to be periodic. Fig. 1 shows the structure and lattice functions of two typical modules with 4B and 5B respectively. The difference between these two modules is whether a bending magnet is put at the middle of the module for further adjustment of the ϵ_x and α_p.



(a) A module with 4B (b) A module with 5B

Figure 1: Typical $\alpha_p < 0$ modules and the lattice functions.



(a) Ratio of ϵ_x (b) Ratio of α_p

Figure 2: Ratio of ϵ_x and α_p as functions of $\xi = D_a/D_F$ for $\alpha_p < 0$ modules(Solid line for modules with 4B and dashed line for modules with 5B).

Note that the dispersion at the entrance of the module is negative, with the $\beta' s$ being the same as that of the FODO cell. By adjusting the negative dispersion properly, both the α_p and ϵ_x can be changed in a quite large range. To compare with the FODO cell case, $\xi = D_a/D_F$ is defined as the ratio of the dispersion function at the entrance of the module to that at the center of the focusing quadrupole for the regular FODO cell. Using the transfer matrix, we can calculate the ratio of the contribution to ϵ_x and α_p between a module and a FODO cell, shown as Fig. 2. In the region of $-1.5 < \xi < -1.0$, the ϵ_x is 2 to 3 times larger in the case of the $\alpha_p < 0$ module than in the FODO cell case, but $|\alpha_p|$ smaller. So we consider adopting the modules to compose the arc region of a $\alpha_p < 0$ TCF lattice.

3 $\alpha_P < 0$ LATTICE FOR A TCF

In terms of the goals of a TCF accelerator[6], the lattice is designed to take the high luminosity mode as the first priority, meantime to be compatible with the polarized beam collision mode and the monochromator mode. Thus the lattice must have enough flexibility, which means that the betas, dispersion functions at the interaction point(IP) can be adjusted easily, the emittance can be varied in a fairly large range and the energy spread be adjusted. We adopt the two rings configuration similar to the Beijing Tau-charm factory(BTCF)[6]. It is used to divide each ring into three parts: Interaction Region(IR), ARC and Utility Region. The polarization insertion is not included here. The betas, dispersion functions at IP depend on the IR design, and the emittance and energy spread mainly rely on the ARC. IR is very complex, however, we can refer to that of BTCF. In the following, we will focus on the design of the ARC to realize $\alpha_p < 0$ for a TCF. The main lattice parameters of the high luminosity mode and monochromator mode for the $\alpha_p < 0$ TCF are listed in Table 1.

3.1 High luminosity mode

For IR, the magnet layout as well as the lattice functions is similar to that of BTCF. Two beams collider with a small horizontal crossing angle of 2.6mrad.

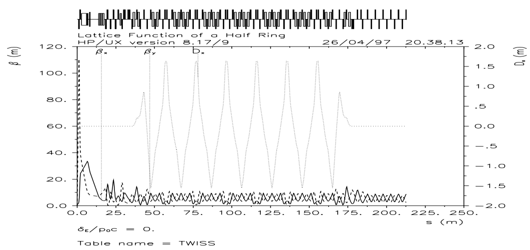


Figure 3: Lattice functions in a half ring of high lum. mode.

The arc region consists of six 4B modules with one dispersion suppressor at each end of it. The betatron phase advance in each module is matched to 300°, so the distortion functions of the chromaticity correction sextupoles can cancel for every block of six modules, that will be of help to the dynamic aperture. The length of each normal bending magnet is 1.1m with bending angle $6.428°$. The drift space of 0.6m is provided for hardware between the dipole and the quadrupole. There are 9 families of sextupoles used for chromaticity correction.

Table 1: Main lattice parameters for the $\alpha_p < 0$ TCF.

Mode	High Lum.	Mono.
Circumference (m)	425.4	425.4
Normal Energy (GeV)	2.0	1.55
Crossing angle at IP (mrad)	2.6×2	0.0
Beta-functions at IP (m) Hori./Vert.	0.65/0.01	0.01/0.15
Dispersion-functions at IP (m) Hori./Vert.	0.0/0.0	0.0/0.35
Natural horizontal emittance (nmrad)	210	126 56(with wig.)
Vertical emittance (nmrad)	3.2	4.0
Tunes,Hori./vert.	17.8/17.8	18.2/15.2
Natural chromaticities, H/V	-26.1/-49.1	-42.0/-39.6
Momentum compaction	-0.0094	-0.0098
Momentum spread (10^{-4})	5.4	8.0(with wig.)
Damping time,H/V/Long.(ms)	36/38/19	33/75/110
Number of bunches	102	35
Particle per bunch (10^{10})	6.1	5.1
Beam-beam parameters ξ_x/ξ_y	0.033/0.033	0.014/0.011
Luminosity ($10^{33}cm^{-2}s^{-1}$)	1.0	0.1
Energy spread at CM (MeV)	1.5	0.12

The utility region lies on the side opposite from the IR. It consists of 10 regular FODO cells as well as two beta matching sections. Utility elements such as kickers and RF cavities are arranged in this region. The working points can be adjusted in the region.

The ring is two-fold symmetric, and the lattice functions of a half ring are shown in Fig. 3.

The dynamic aperture is investigated by tracking study with MAD[7]. Except for the chromaticity sextupoles, no other correctors have been installed into the linear lattice. Chromaticities in both planes are corrected to 0. Fig. 4 is the preliminary results of simulation in six dimensions. The dynamic aperture without magnet errors at collision is larger than $12\sigma_x \times 12\sigma_y$ at energy spread of 0.6%.

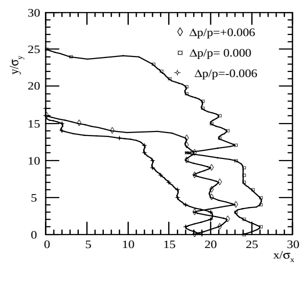


Figure 4: Dynamic aperture of the high lum. mode.

3.2 Monochromator mode

Similar to the consideration for BTCF, the monochromator mode has been combined into the design of the high luminosity mode with opposite vertical dispersion for two beams introduced at IP and Robinson wigglers used to provide the ability of adjusting the emittance and energy spread. Fig. 5 shows the lattice functions in a half ring. Tentative study result show that the dynamic aperture is

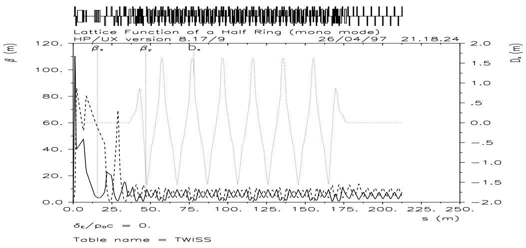


Figure 5: Lattice functions in half ring of monoch. mode.

about $10\sigma_x \times 10\sigma_y$ at $\delta p = \pm 0.008$, and Touschek lifetime about 1 hour. Further study is needed.

4 FLEXIBILITY OF THE LATTICE

The emittance of the lattice can be varied in a fairly large range. Particularly, when the dispersion at the entrance of the module is matched to -2.5m, emittance is increased to 320nmrad which is appropriate for the so called standard mode of a TCF. But the synchrotron oscillation tune $Q_s = 0.064$ is smaller than the previous $\alpha_p > 0$ case. The phase advance in a module is kept as $300°$, so the dynamic aperture does not decrease during the variation.

In addition, by matching the strength of the quadrupoles in the ARC, the positive dispersion is achieved for $\alpha_p > 0$. Fig. 6 shows the lattice functions of a half ring. Since the lattice parameters is chosen similar to that of BTCF, the high luminosity can be promised. Thus the version of an $\alpha_p > 0$ TCF is reserved with the same magnet layout.

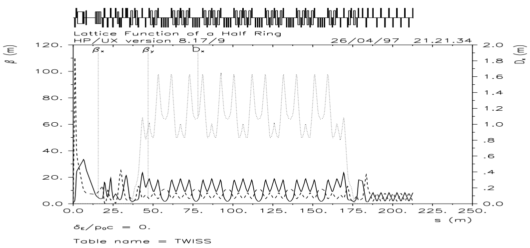


Figure 6: Lattice functions in half ring with $\alpha_p > 0$.

5 INSTABILITY AND BUNCH LENGTHENING

The single bunch effects are relative severe in a TCF[6]. The bunch lengthening effect, which arises from the distortion of particle distribution within a bunch with beam current increase, relates to α_p, so we pay much attention to it. For multi-bunch effects, the bunch is usually considered as an point charge, so there is no difference between in the $\alpha_p < 0$ case and the $\alpha_p > 0$ case. We can follow the conclusion got in the feasibility study of BTCF: the multi-bunch instability will not affect the feasibility.

The bunch lengthening vs beam current is simulated with the code developed by K. Oide and K. Yokoya[8]. (see Fig. 7). The longitudinal wakefield used in simulation is similar to that got in the BTCF feasibility study. The designed

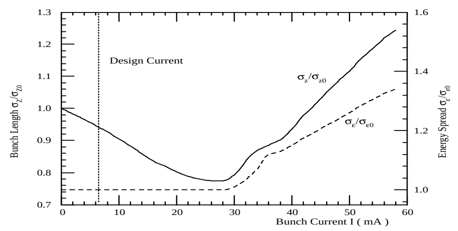


Figure 7: Bunch lengthening vs beam current(Solid line for bunch length and dashed line for Energy spread).

single bunch current of 6.8mA is far below the microwave instability threshold, which is around 16mA. The bunch length at the design current is shorter than the natural rms length i.e. no bunch lengthening occurs. The reason can be understood that, in the present TCF design, though the natural bunch length is quite short, about 1cm, the beam still feels the inductive impedance in the case of $\alpha_p > 0$. Correspondingly, the beam feels negative inductive impedance in $\alpha_p < 0$ case, that leads to bunch shortening. Simulation done for the standard mode gives the similar conclusion. The designed current is below threshold, with no bunch lengthening.

6 CONCLUSION AND DISCUSSION

From the view point of lattice parameters and beam stability, it's feasible to design an $\alpha_p < 0$ lattice for a TCF. Optimization of the lattice is under way.

Experiments on Super-ACO[9] have confirmed that Bunch lengthening was weaker in the case of $\alpha_p < 0$. But the energy spread seemed to increase faster than in the case of $\alpha_p > 0$. Recent study[10] shows that when dispersion at the interaction region is introduced with $\alpha_p < 0$, there is large safe area in the parameter space for beam-beam effect. That might be a virtue for adopting $\alpha_p < 0$ lattice in the monochromator mode. Further research on the beam physics with $\alpha_p < 0$ lattice is worthwhile.

7 ACKNOWLEGEMENTS

The author would like to thank Prof. N. Huang for her kind help on the lattice design of the IR.

8 REFERENCES

[1] J. Le Duff, CERN 95-6, p515.

[2] S.X. Fang et al, Part. Accel., Vol. 51, 1995, pp. 15-28.

[3] J.Q. Wang, Ph. D. thesis, July 1997.

[4] L.C. Teng, Part. Accel., Vol. 4, pp. 81-85

[5] S.Y. Lee et al, Phy. Rev., Vol. 48, No. 4, Oct. 1993.

[6] IHEP-BTCF Report-03, Oct. 1996.

[7] H. Grote, F.C. Iselin, CERN/SL/90-13(AP), 1990

[8] K. Oide and K. Yokoya, KEK Preprint 90-10, 1990.

[9] A. Nadji et al, EPAC'96, June 1996.

[10] S. Petracca and K. Hirata, KEK Preprint 96-162, Jan. 1997.