TBA and DBA Magnet Lattices for Tau-Charm Factory

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Abstract

Magnet lattice designs of tau-charm collider, based on use of TBA and DBA cells in arcs are consideredr. To fulfil requirements of tau-charm physics each lattice provides two modes of collider operation. One uses conventional scheme at interaction point and needs in high emittance. Other provides monochromatization at interaction point and requires small emittance. It is shown that both TBA and DBA lattices allow to have emittance in wide range from 10 nm up to 400 nm. Careful choice of arc cell tunes, as well as arc design was made to make chromaticity correction easier. Details of chromaticity correction for both TBA and DBA lattices for high and low emittance mode are considered. As a result, comparison of collider parameters with TBA and DBA lattices is performed.

1 INTRODUCTION

It is generally accepted now that tau-charm factory (TCF) has to be designed with high flexibility to fulfil physics requirements [1], [2]. The collider design has to provide operation with standard scheme at interaction point (I. P.), as well as could be transformed with some modifications to a scheme with monochromatization of colliding beams and (or) to a scheme with finite crossing angles. The ability of a collider to operate in different modes is connected closely with the value of the emittance defined by its magnet lattice. To get high luminosity

$$L = \frac{\gamma I}{2er_0}\left(\frac{\xi_x}{\beta_x^\star} + \frac{\xi_y}{\beta_y^\star}\right) \qquad (1)$$

at the level of 10^{33} cm^{-2} s^{-1} with a conventional scheme it is necessary to have a natural emittance $\varepsilon_0 \simeq 300\div400$ nm at the energy E=2.0 GeV. Here $\gamma = \mathrm{E/mc}^2$, I is the total beam current, $\xi_{x,y}$ are beam-beam parameters, $\beta^\star_{x,y}$ are the beta functions at I. P.

To keep luminosity with monochromatizations of the beams at I. P. at the same level, the micro-beta quadrupole strengths must be reversed to get low $\beta_x^\star$ instead of low $\beta_y^\star$ and high ξ_x instead of high ξ_y. The horizontal emittance is restricted by the condition

$$\epsilon_x \leq \beta_x^\star(\sigma_E D_y^\star/\beta_y^\star)^2. \qquad (2)$$

For typical TCF parameters [1] one gets $\epsilon_x \leq 20\div30$ nm at the energy E=2.0 GeV. Hence, TCF magnet lattice must be designed very flexible to allow an emittance change from 400 nm to 20 nm, i.e. a factor 20 [3]. TBA and DBA lattices are very attractive for this purpose, because allow easy emittance change by mismatching of dispersion D_x and readjusting β_x in the bending magnets. Their studies showed very good properties in the low emittance mode, but the dynamic aperture in high emittance mode was found too small [4]. Few variants of its improving are discussed below. The calculations have been performed keeping the interaction region and the vertical separation region optics the same as in the FODO lattice case[3].

2 CHOICE OF ARC CELL PARAMETERS

2.1 Arc cell tunes

For intrinsic cancellation of driving terms exited by normal sextupoles located in N_c arc cells their tunes $\nu^c_{x,y}$ must to fulfil

$$nN_c\nu_x^c = l, \quad N_c(\nu_x^c \pm m\nu_y^c) = l, l \neq jN_c,$$
$$l, j - \text{integers}, \quad n = 1, 3, \; m = 0, 2. \qquad (3)$$

Half-integers $\nu^c_{x,y}$=(2l+1)/2 must be excluded from (3) as unacceptable for correction of chromatic distortions of beta functions and their derivatives. For TCF with circumference of 360÷380m and insertion length of 65÷70m arc is about 120m long [3], hence $N_c = 6$ was chosen. This gives for favourable arc cell tunes

$$\nu_x^c = 1/6, \; 5/6, \; 7/6, \; 11/6, ...,$$
$$\nu_x^c \pm 2\nu_y^c = \pm(1/6, \; 2/6, \; 3/6, \; 4/6, \; 5/6, \; 7/6, ...). \quad (4)$$

2.2 TBA and DBA arc cells for low emittance mode

The horizontal tune per arc cell ν^c_x=7/6 is the best one for TBA and DBA low emittance lattice from those fulfilling (4). It provides $\epsilon_x = 7\div10$nm at the energy E=1.55 GeV. For the vertical tune, ν^c_y=1/3 is the smallest value among those fulfilling (4) and provides good optical solution. Lattice functions for half TBA cell are shown in Fig. 1. The strengths of three quadrupoles in the dispersion region between left(right) and central bending magnets were adjusted in a way to have two approximately equivalent positions for location of the defocusing sextupoles. This enables to use three chromatic sextupole families (one focusing and two defocusing) instead of two, with substantially bigger dynamic aperture (section 3).

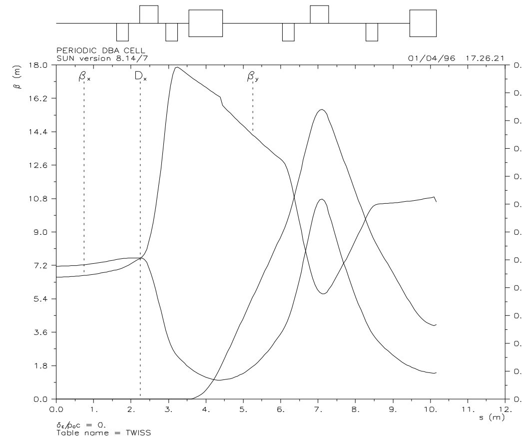

Figure 1: Lattice functions for TBA arc half cell in low emittance mode.

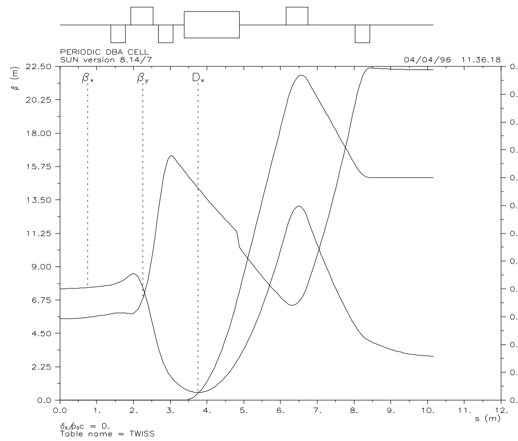

Figure 2: Lattice functions for DBA arc half cell in low emittance mode.

Standard DBA cell with matching triplets at the cell ends and four quadrupoles between bending magnets were investigated for the TCF low emittance mode. The lattice functions are shown in Fig. 2.

2.3 *TBA and DBA arc cells for high emittance mode*

The only suitable horizontal tune per arc cell for high emittance lattice is ν_x^c=5/6. To get it with TBA or DBA cells, dispersion is mismatched at arc cell ends, and quadrupols are readjusted to have high β_x at the left and right bending magnets. With constraint in 40mm on horizontal aperture of vacuum chamber $\beta_x \simeq 20 \div 25$m in magnets, that gives $\epsilon_0 \simeq 200 \div 250$nm. To increase the emittance further, wigglers are located in the first and last arc cells. For equal emittance increase, Robinson wigglers introduce smaller perturbations in the beta functions, than dipole ones, hence

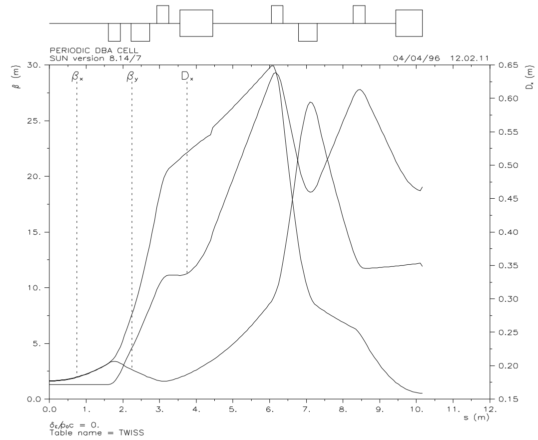

Figure 3: Lattice functions for TBA arc half cell in high emittance mode (ν_x^c=5/6, ν_y^c=5/6).

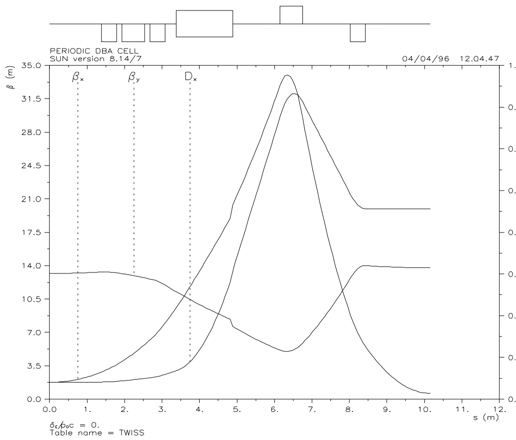

Figure 4: Lattice functions for DBA arc half cell in high emittance mode (ν_x^c=5/6, ν_y^c=1/3).

they were used. Four Robinson wigglers, 0.8m long, with magnetic field of 0.72T and gradient 9 T/m are required to decrease the damping partition number J_x from 1 to 0.5 and to get an emittance of about 400 nm.

Dispersion matching at the arcs is performed by readjusting quadrupoles at marginal half-cells. Then two cells are different from the other four in each arc. With high beta functions at sextupole positions the driving terms are increasing strongly. To keep them at a tolerable level, dispersion matching must be performed very carefully. The value of the dispersion at the ends of each cell must be kept small, $D_x \le$0.25m, excepting marginal ones, where it is zero. This puts constraints on the vertical tune of the cell. The favourable are ν_y^c=5/6 for TBA and $\nu_y = 1/3$ for DBA.

3 CHROMATICITY CORRECTION AND DYNAMIC APERTURE

For the low emittance mode the dynamic aperture is tolerable with two sextupole families ($23\sigma_x/20\sigma_y$ for TBA and $24\sigma_x/26\sigma_y$for DBA lattices). It can be essentially enlarged by adding one defocusing sextupole family in TBA cells ($34\sigma_x/43\sigma_y$) and one sextupole family in zero dispersion region of DBA cells ($29\sigma_x/35\sigma_y$).

For the high emittance mode, with Robinson wigglers switched on and $\epsilon_0 \simeq$ 400nm, the dynamic aperture with two families is $11\sigma_x/18\sigma_y$ for TBA and $12\sigma_x/20\sigma_y$ for DBA lattices. The main limiting factor is strong dependence of the horizontal tune with the horizontal amplitude.

Few variants of the dynamic aperture improving have been studied. In the first one the possibilty of location of the additional sextupole families into the arcs cells were explored. For successfull correction the additional families must be well separated in horizontal phase advance from the other ones and be located where the horizontal beta function is large. It is seen from Fig. 3, that there are no such positions.

The second variant is to locate an additional sextupole family into 8 cells of the utility straight section. With phase advances in these cells $\nu^{ss}_{x,y} \simeq \pi/2$ (intrinsic cancellation of the resonances) it is possible to enlarge the horizontal dynamic aperture significantly. The disadvantage of this solution is that phase advances per straight section cell are frozen.

The third variant is to use octupoles located in regular cells to compensate horizontal tune shifting with amplitude. With cell tunes $\nu^c_{x,y}$=5/6 the octupoles don't exite new resonances in the lowest order. The use of one octupole family helps significantly and increases the dynamic aperture up to $22\sigma_x/19\sigma_y$ for TBA and $18\sigma_x/23\sigma_y$ for DBA lattices. The octupole positions and their integrated strength $B'''l/B\rho$=-16m^{-3} for TBA and $B'''l/B\rho$=8m^{-3} for DBA and were defined by tracking (l=0.2m is the octupole length). Note that the required octupole strength is small and corresponds to the magnetic pole tip field of 0.08 T at the energy of 2 GeV.

4 COMPARISON OF LATTICES

Both TBA and DBA lattices can be considered as candidates for TCF as well as the FODO lattice. Parameters of TBA and DBA lattices are very similar (their list is given in Table 1). Both lattices are very convenient for low emittance mode of operation, and promise easier chromaticity correction compared with the FODO lattice because they have 6 sextupole families instead of 4 for FODO, hence larger dynamic aperture and beam lifetime. They are also suitable for the high emittance mode of operation, with a tolerable dynamic aperture although smaller than the FODO lattice.

Table 1: Parameter list for a tau-charm collider

	TBA LE	DBA LE	TBA HE	DBA HE
E, GeV	1.5	1.5	2.0	2.0
C, m	378	378	378	378
ϵ_0, nm	11.8	14.8	378	391
ϵ_y, nm	2	2	18	19
ρ, m	6.2	5.7	6.2	5.7
$\alpha \cdot 10^3$	1.49	1.29	6.18	5.13
$\sigma_E \cdot 10^4$	5.17	5.37	6.19	6.38
I, mA	159	184	498	525
k_b	30	30	30	30
V_{RF}, MV	0.5	0.5	4	4
f_{RF}, MHz	476	476	476	476
σ_s, mm	6.73	6.50	6.70	6.29
$\mid Z_n$/n$\mid$, Ohm	0.032	0.025	0.092	0.072
$\beta^\star_x/\beta^\star_y$, cm	1/15	1/15	20/1	20/1
D^*_y, m	0.36	0.36	0.	0.
ξ_x	0.04	0.04	0.04	0.04
ξ_y	0.026	0.027	0.04	0.04
σ_w, MeV	0.106	0.102	1.75	1.80
L$\cdot 10^{33}$ cm $^{-2}$s^{-1}	0.22	0.25	0.91	0.96

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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