

INTERACTION SECTION LATTICE DESIGN FOR A STCF PROJECT

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Abstract

The Super Tau-Charm Factory (STCF) planning in China is characterized with high luminosity, wide energy range and high longitudinal polarized electron beam. In order to achieve high luminosity, this project will adopt the recently proposed collision scheme based on Large Piwinski angle and Crab Waist. In this paper, a preliminary lattice design of interaction region meeting the above collision scheme is described.

INTRODUCTION

The STCF [1] is a double-ring structure. The electron and positron beams circulate around two separate rings and intersect at a single interaction point where detector is placed. The two rings have the same lattice structure, except that the electron storage ring will install several Siberian Snakes to get longitudinal polarized beam at the interaction point.

The luminosity for a flat beam can be described as follow,

$$L = \frac{\mathcal{H}_0}{2r_e} \frac{N_b}{\beta_y^*} \xi_y \quad (1)$$

with γ the relativistic factor, f_0 the revolution frequency, r_e the classical radius of electron, N_b the number of particle per bunch, β_y^* the vertical betatron function at the interaction point and ξ_y the vertical beam-beam parameter. Compare with the traditional collision scheme the Crab Waist (CW) [2] and Large Piwinski Angle collision makes it possible to increase N_b/β_y^* by more than one order of magnitude and increase ξ_y by two or three order of magnitude without bunch length and beam current reduction [3]. Thus the luminosity will increase several orders of magnitude. Experimental test of the novel scheme has already been confirmed at DAΦNE, the Italian Φ factory in 2010 [4].

The main parameters of the STCF project are listed in Table 1. These parameters are chosen in order to get a peak luminosity of $1 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$ required by the physics case study. The center of mass energy range is 2-7 GeV. Optimized energy of this paper is 4 GeV. The circumference of this STCF is planned to be about 600 m among which ten dispersion free long straight sections are reserved to install Siberian Snakes and damping wigglers.

Table 1: Main Parameters of the STCF Project

Parameters	value
Circumference [m]	~600
Optimized energy (center-of-mass) [GeV]	4
Current [A]	1.5
Collision angle [mrad]	60
Hour-glass factor	0.8
Luminosity [$\text{cm}^{-2}\text{s}^{-1}$]	1×10^{35}
β_y^*/β_x^* [mm]	0.6/60

The CW collision scheme requires strong final quadrupole to minimize the vertical betatron function at IP, which is in the order of sub millimetres. This very small vertical betatron function leads to that the vertical betatron function grows rapidly and then cause very large vertical chromaticity. In order to reduce the negative effect of sextupole, local chromaticity correction scheme with $-I$ transformation is employed. Additionally, the crab sextupoles require special phase advances from IP to the crab sextupole, as well as specific betatron function at crab sextupole position to reduce the strength of the sextupole. The above constraints cause that, the interaction region with CW scheme to be one of the important and difficult areas. In this paper we give a detailed linear optics design process of the interaction section.

The block diagram of the interaction region is shown in Figure 1. It composes of four parts: (1) The final focus system is designed as a telescope. (2) The chromaticity correction section, including vertical chromaticity correction section and horizontal chromaticity correction section, is designed for local chromaticity compensation. (3) Following that is the crab sextupole section. At the beginning of this section the dispersion function and its derivative are set to zero with a bending and four quadrupole magnets. Then, two triplets are used to adjust the horizontal and vertical tunes which satisfy the crab sextuple requirement. (4) Finally, we use six quadrupoles to compose another telescope (from IP to the end of the interaction region).

Total length of the interaction region is 103.8 m and the total bending angle is 36° .

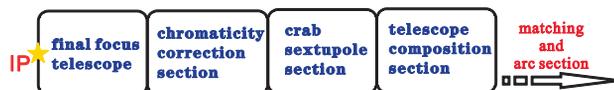


Figure 1: Block diagram of the STCF interaction section.

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OPTICS DESIGN

Final Focus Telescope

Since a flat beam is desired in the STCF project, so that the last lens module nearest to the IP is a quadrupole doublet structure [5]. The chromatic distortion caused by the final focus section is a function of the distance L^* from first lens to the IP. The smaller L^* is, the smaller chromatic distortion is. However, too small L^* makes the detector hard to install. Compromise between the chromatic distortion and the space of detector installation, $L^*=0.6$ m is chosen in this paper. The total length of the final focus doublet is 1.8 m. Following the doublet a bending magnet with 1 m length and 0.01 rad bending angle is placed for dispersion driving. This is because the local chromaticity correction method needs non-zero dispersion function at the interaction region. After the final focus doublet, another doublet is placed at the location 3.2 m away from the first doublet to make the final focus to be a telescope, which means that the linear transport matrix of both planes satisfy the following form,

$$M_{x,y} = \begin{pmatrix} K_{x,y} & 0 \\ 0 & 1/K_{x,y} \end{pmatrix} \quad (2)$$

where $K_{x,y}$ is the conversion factor. The phase advances from IP to the end of the final focus telescope are equal to π for both transverse planes. In all, the total length of the final focus telescope is 8.1 m.

Chromatic Correction Section

The chromaticity generated by the final focus lens can be estimated by the following equation,

$$\xi^* = -L^* / \beta^* \quad (3)$$

where β^* is the betatron function at IP. In the CW collision scheme β^* is always very small. In our design $\beta_y^* = 0.6$ mm and $\beta_x^* = 60$ mm, which means that the chromaticity, especially the vertical chromaticity generated by the final focus is very large. Since the particle beams are not mono-energetic but have a finite momentum spread, it is necessary to locally compensate the large chromaticity produced by the final focus quadrupoles. However, the strong chromaticity correction sextupole always leads to the focusing structure to be high nonlinear system and thus degrades the dynamic aperture. Fortunately, sextupole pair (with zero length) separated by a minus unity optical transform does not generate second-order geometric aberrations [6] and is beneficial to dynamic aperture. Based on this, a pair of sextupoles for chromaticity correction is placed near to the final focus telescope. The two sextupoles are connected by $-I$ transformation matrix, and the phase advance between them is

$\Delta\phi_y = \pi$. Meanwhile, at the position where the vertical chromaticity correction sextupoles are placed the ratio of β_y / β_x is designed to be as large as possible (in our design $\beta_y / \beta_x \approx 162/8$). For effectively correct the chromaticity the dispersion function is expected to be higher where the sextupole is placed. Hence, a stronger bending magnet is placed after the final focus telescope to drive higher dispersion function for efficiently chromaticity compensation.

After the vertical chromaticity correction section is the horizontal chromaticity correction section. This section is also designed to be $-I$ transformation. The horizontal phase advance between two sextupoles is also $\Delta\phi_x = \pi$, and the ratio of beta beat is $\beta_x / \beta_y \approx 55/1$.

Crab Waist Section

The crab sextupoles placed at a proper phase advance location from IP will rotate the position of the vertical betatron function along the axis of the opposite beam, and suppress synchrotron-betatron resonances [5]. If the phase advance and field gradient are chosen appropriately the second order geometric aberrations will be canceled by each other. Namely that, the horizontal phase advance between the crab sextupole and IP is integer times of π while the vertical phase advance is half integer times of π (as shown in Figure 2).

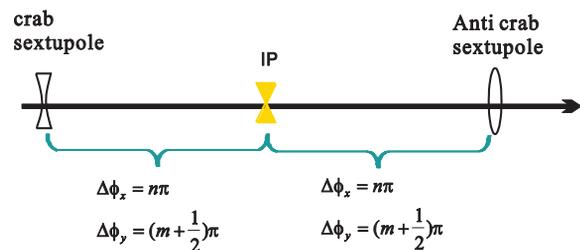


Figure 2: Phase advances need by the CW collision.

The integrated strength of crab sextupole should satisfy the following equation,

$$K_2 L = \frac{1}{2\theta\beta_y^* \beta_y} \sqrt{\frac{\beta_x^*}{\beta_x}} \quad (4)$$

where β_x and β_y are horizontal and vertical betatron function at the place where crab sextupole is implemented, and θ is the collision angle.

Telescope Composition Section

After the crab sextupoles section, 6 quadrupoles are placed. They are used to form the section from IP to the end of the interaction section also be a telescope. The merit of the telescope design is that the betatron function

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of the IP can be adjusted by changing the quadrupoles of the matching section while all of the elements inside the telescope remain unchanged. Also, the phase advance of $-I$ transformation and crab sextupoles requirement remain unchanged.

RESULTS

Summarizing the above consideration, we get the total interaction region magnet arrangement and corresponding optics function as shown in Figure 3.

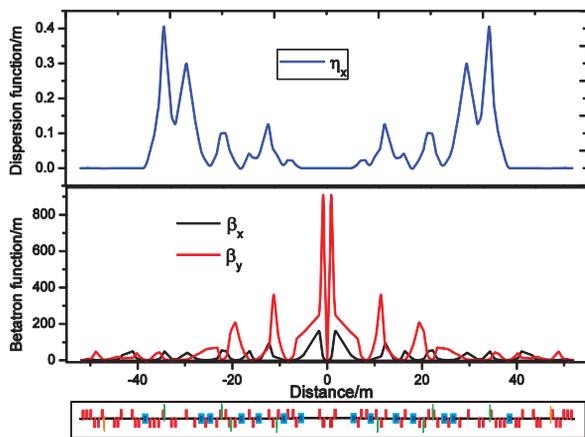


Figure 3: Horizontal dispersion function (top) and betatron function (bottom) of the total interaction section.

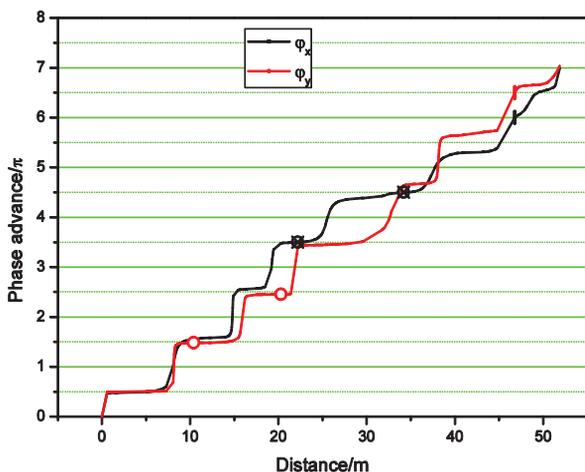


Figure 4: the horizontal phase advance (black line) and vertical phase advance (red line) from IP to the end of the interaction section.

The phase advance is particular important for the interaction region with CW collision and local chromaticity correction as well as the telescope formation. The phase advance from IP (at the origin of coordinate) to the end of the interaction section is shown in Figure 4. The vertical chromaticity correction sextupoles are located at the places signed with red dots, the horizontal chromaticity correction sextupoles are located at the places signed with

black dots, while the crab sextupoles are located at the place indicated by a small vertical line. From the figure we see that the phase between IP to the end of the interaction section is 7 times of π for both planes.

CONCLUSION

We design the interaction region lattice in this paper. The arc section as well as the nonlinear optics will be designed in our future work.

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