CONCEPTUAL DESIGN FOR THE COMBINED DAMPING AND ACCUMULATOR RINGS FOR POSITRONS AT STCF

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Abstract

The Super Tau-Charm Facility (STCF) is a new generation tau-charm factory designed to collect an enormous and unique dataset in the tau-charm energy region. In order to supply high-quality electron and positron beams to the collider, the STCF injector employs a compatible injector scheme that supports both off-axis and swap-out injection modes. This paper introduces the conceptual design of a combined damping and accumulator rings for positrons at the STCF, aimed at meeting low-emittance beam requirements. The damping ring (DR) and the accumulator ring (AR) share the same lattice, and aligned vertically to reduce construction costs. The detailed lattice design of the DR and AR are presented in this paper.

INTRODUCTION

For the Super Tau-Charm Facility (STCF) [1], to deliver high-quality, full-energy electron and positron beams to the collider rings (CRs), two parallel CR injection schemes are currently under consideration: off-axis injection and swap-out injection. The STCF injector adopts a compatible injector layout scheme, and its layout varies depending on the CR injection mode. For off-axis injection, positron beams are injected into the damping ring (DR), damped, and then extracted to the main Linac. For swap-out injection, positron beams are first damped in the DR, accumulated in the accumulator ring (AR) over three cycles, and finally transported to the ML for acceleration. The AR adopts the same lattice design as the DR. This consistency allows the two rings to be stacked vertically, as shown in Fig. 1. With the exception of the injection sections, all components are aligned vertically one-to-one, enabling both rings to share the same tunnel without a separate enclosure for the AR, thereby significantly reducing construction costs.

In the design of the STCF, the beam energys of positron in both DR and AR are 1.0 GeV. The geometric emittance of the bunch injected into the DR is 1400 nm·rad. According to the design of the STCF CR, the injected positron bunch emittance must be below 6 nm·rad at the nominal energy of 2.0 GeV. This corresponds to a maximum emittance of 12 nm·rad at 1.0 GeV. To meet the injection requirements of the STCF CRs and account for emittance growth during transport, the geometric emittance of the extracted bunch

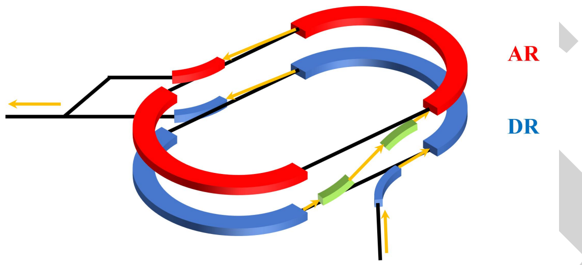

Figure 1: Layout of the DR and the AR. Two rings are stacked vertically, sharing the same lattice and the extraction transport line.

must be less than 11 nm·rad for the off-axis injection scheme with a repetition rate of 30 Hz, and be less than 30 nm·rad for the swap-out injection scheme with a repetition rate of 90 Hz. Main parameter requirements of the two injection schemes are shown in Table. 1.

This paper presents the detailed lattice designs of the STCF DR and AR. Since the lattices of the DR and AR are identical, they are collectively referred to as the STCF DR lattice in the following text. The lattice design was carried out using the MAD-X [2] and OPA [3] codes.

LINEAR OPTICS

To reduce the extraction emittance below 11 nm·rad, the beam must be stored in the DR for at least three damping times, and the natural emittance must be less than 10 nm·rad. To reduce the tunnel construction cost, the STCF DR lattice requires a small ring circumference. The current STCF DR meets these goals with a total circumference of 152.4 m, comprising two large arc sections and two long straight sections. The natural emittance of the DR is 9.64 nm·rad. At a repetition rate of 30 Hz, the DR is designed to store either 6 or 12 bunches, thereby satisfying the design specifications. The 6-bunch mode corresponds to an off-axis injection scheme, while the 12-bunch mode is intended for a swap-out injection scheme. Two long straight sections are used for injection and extraction, respectively.

The STCF DR lattice adopts the arc-section FODO design with reverse bends, as used in the SuperKEKB DR [4] and the CEPC DR [5]. Each large arc section consists of 18 FODO cells. Each FODO cell has a length of 2.74 m, a phase advance of 90° / 90° (horizontal / vertical), and a total bending angle of 9°. The ratio of the reverse bending angle to the forward bending angle is set to 0.3. The forward bend

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Table 1: Key Parameters of STCF Injector

Parameters	Off-Axis	Swap-Out	Unit
Electron gun type	Photo-/thermionic cathode	Thermionic or PITZ	
Linac RF frequency	2998.2	2998.2	MHz
Bunch charge into collider	1.0	8.5	nC
Injection energy/nominal energy	1.0-3.5/2.0	1.0-3.5/2.0	GeV
Injected electron bunch geometric emittance (X/Y, rms)	≤6/2	≤30/15	nm·rad
Injected positron bunch geometric emittance (X/Y, rms)	≤6/2	≤30/15	nm·rad
Injected bunch energy spread (rms)	≤0.1	≤0.5	%
Injected bunch length (rms)	<7	<7	mm
Repetition rate (electron)	30	30	Hz
Repetition rate (positron)	30	30	Hz
Positron ring	DR	DR+AR	-
Bunch charge at ring entrances	1.0	2.9	nC
Emittance at ring entrance (X/Y, rms)	≤1400	≤1400	nm·rad
Energy spread at ring entrance (rms)	0.1	0.3	%
Emittance at ring exit (X/Y, rms)	≤11/0.12	≤30/10	nm·rad

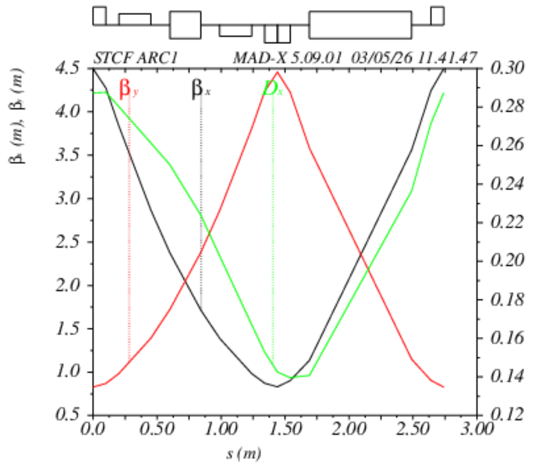

Figure 2: Linear optics of one STCF DR arc section.

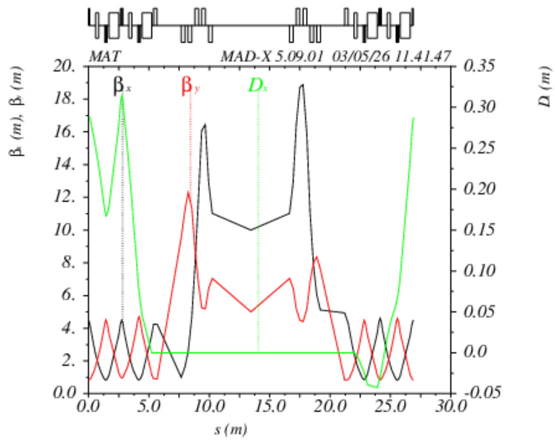

Figure 3: Linear optics of one STCF DR straight section.

has a length of 0.8 m, and the reverse bend has a length of 0.24 m; both bending magnets share a bending radius of 3.565 m and a magnetic field strength of 0.936 T. The linear optics of the arc cell is shown in Fig. 2.

In the STCF DR, two FODO cells are used for dispersion match. These cells contain both forward and reverse bends, each at half the strength of those in the standard arc FODO cell. After these dispersion match cells, there is a long straight section with a length of 16.12 m, which is used for injection/extraction and houses the RF cavity. The Twiss parameters of this region are shown in Fig. 3, where the horizontal and vertical β functions at the midpoint are 10 m and 5 m, respectively.

The full-ring layout and the linear optics of the STCF DR are shown in Figs. 4 and 5, respectively. The key parameters of the STCF DR is listed in Table. 2.

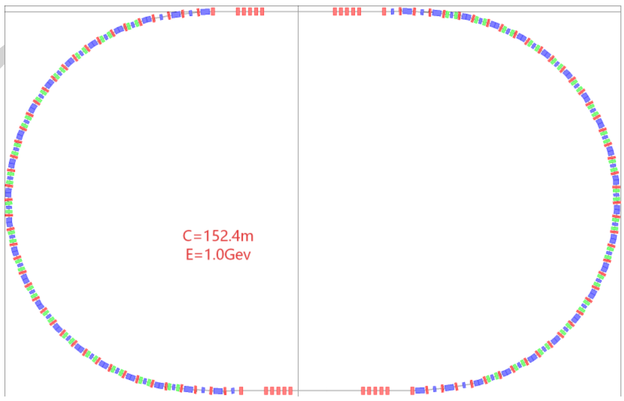

Figure 4: Layout of the STCF DR.

NONLINEAR OPTIMIZATION

Considering that each arc section consists of 18 cells and each cell has a phase advance of 90°/90°, the 18 cells are divided into 6 groups. Among them, four groups each contain 4 periodic cells, forming a supercell with a horizontal

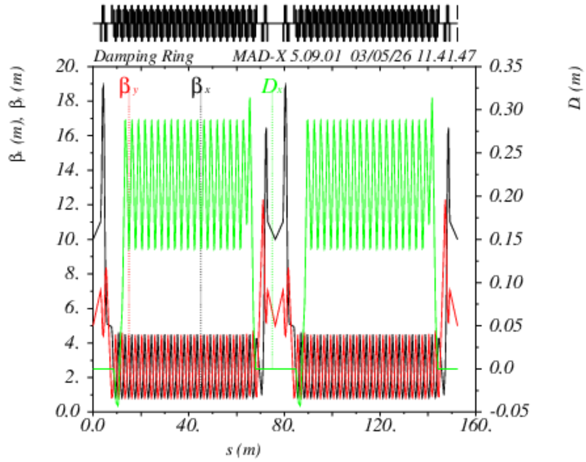

Figure 5: Linear optics of STCF DR full ring.

Table 2: Key Parameters of STCF DR

Parameter	Value
Energy (GeV)	1.0
Circumference (m)	152.4
Number of bunches	6
Max charge per bunch (nC)	1.5
Arc FODO phase advance x/y (deg)	90 / 90
Dipole bending radius (m)	3.565
Dipole field strength (T)	0.936
Reverse bend factor	0.3
Energy loss per turn (keV)	43.8
Damping time x/y/z (ms)	23.5 / 23.2 / 11.6
Storage time (ms)	200
Natural emittance (nm·rad)	9.64
Injection emittance x/y (nm·rad)	1400 / 1400
Extraction emittance (nm·rad)	9.6401
Natural relative energy spread (%)	0.045
Momentum compaction factor	0.0058
RF frequency (MHz)	499.7
RF voltage (MV)	0.7
Harmonic number	254
Natural chromaticity x/y	-16.7 / -15.1

and vertical phase advance of 360°/360°. In each supercell, different sets of focusing and defocusing sextupoles are installed adjacent to the reverse bends of every individual cell. For the remaining two cells, two additional distinct sets of focusing and defocusing sextupoles are installed. In total, 12 sextupole families are employed in the full ring to optimize the dynamic aperture and chromaticity.The optimization was carried out using the PAMKIT code [6], with sextupoles the variable and chromaticity as the constraint to optimize the dynamic aperture.

Figure 6 shows the dynamic aperture (DA) tracked for 1024 turns by Elegant [7]. The DA exceeds 5 times the rms beam size at the middle of the straight section in both transverse directions, fully meeting the injection requirement.

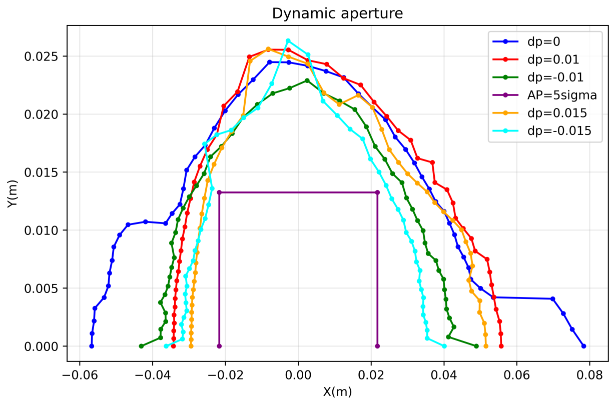

Figure 6: On- and off- momentum DAs of the STCF DR, tracked at the middle of the straight section.

CONCLUSION

In this paper, we present a preliminary lattice design for the STCF DR, which uses FODO cells with reverse bends as the periodic arc cell. The lattice consists of two arc sections and two long straight sections. Both the extraction emittance and dynamic aperture meeting the requirements. Future work will include further lattice optimization and consideration of error effects.

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