STATUS OF THE SSC LATTICE DESIGN

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Abstract

The current status of the SSC lattice design is discussed. The proton-proton collider, consisting of two vertically separated rings, has eight experimental and utility long straight sections located in two clusters. The clusters are separated by two arcs containing 90° phase advance cells. Each cluster is made up of four modules, and each module contains normal cells, dispersion suppressors, and a straight section. The module focusing structure is antisymmetric about the center of the straight section. The 90° cells enhance resistance to field imperfections and allow use of a compact type of dispersion suppressor. The optical design of the experimental straight sections is functionally modular, limits high β-function values to the central triplets, and permits easy tuning between the injection and collision optics, during which the phase interval between neighboring straight sections is fixed at values that minimize chromatic perturbations.

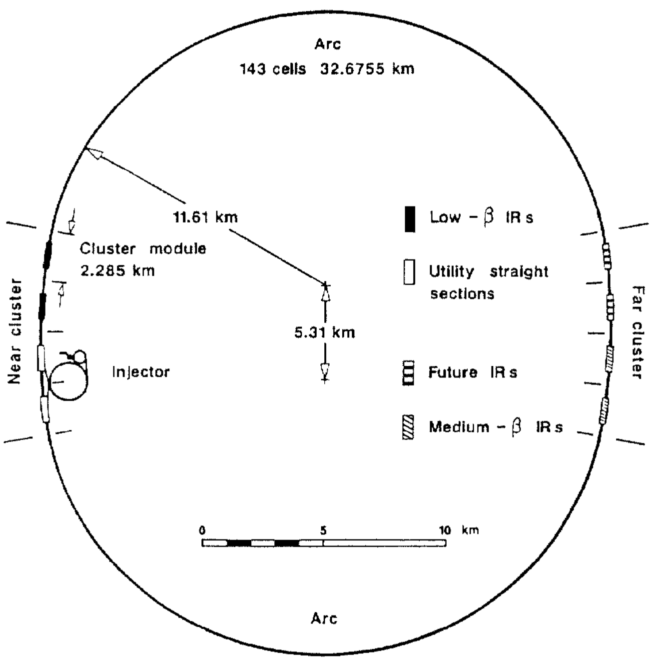

Fig. 1. SSC Ring Layout.

Introduction

Due to the variety of the SSC's experimental and operational requirements, it is critically important that its lattice design accommodate these needs conveniently, while minimizing intrinsic non-linearities, sensitivity of particle motion to errors, and cost. This paper describes the present SSC lattice design, which is similar to that of the Conceptual Design Report,[1] but contains significant differences and improvements. The similarities are independent magnets in separate cryostats, vertically separated rings, focusing antisymmetry, and eight straight sections placed in two clusters. There are important differences in the cell phase advance (changed from 60° to 90°), cell length (changed from 192 m to 228.5 m), dispersion suppressors, and straight sections. The over-under magnet arrangement utilizes tunnel space efficiently, decouples the two rings cryogenically and magnetically, equalizes the path lengths of the two beams between collision points, and makes the two rings essentially identical. The clustered straight section arrangement places most experimental and machine functions in two areas of reasonable size, and it has generally superior orbit properties compared with a distributed arrangement. Principal parameters of the present lattice are shown in Table I, and a detailed description is given in an SSC report.[2]

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Global Structure

The 84-km rings for the two counter-rotating proton beams are placed one above the other; the beamlines are separated by 70 cm. The beamlines cross vertically at interaction points (IPs) located at the centers of four experimental straight sections (IRs). The beams are nearly colinear in the vicinity of the IPs, where they pass through common quadrupoles and vertical beam-splitting dipoles.

Table I Lattice Parameters

Circumference	83.631 km		
Energy: injection, collision	1 TeV,		20 TeV
Cell phase advance	90°		
Betatron tunes ν_x, ν_y	95.28,		95.26
Chromaticity: collision, injection	−219,		−134
Momentum compaction	1.563×10^{-4}		
β_{max}, β_{min} in arc	388 m,		68 m
η_{max}, η_{min} in arc	3.05 m,		1.47 m
β^*, β_{max} in XL, injection	8 m,		1135 m
β^*, β_{max} in XL, collision	0.5 m,		7719 m
β^*, β_{max} in XM, injection	60 m,		870 m
β^*, β_{max} in XM, collision	10 m,		2605 m
β_{center}, β_{max} in U	351 m,		904 m
Drift length at IP in XL, XM	±20 m,		±120 m
Drift lengths in U: center, ends	638 m,		235 m
IP–IP distance, angle	2285 m,		82 mrad
Crossing angle (range)	0	—	150 μrad
Cell, module lengths	228.5 m,		2285 m
Magnetic field, gradient	6.61 T,		230 T/m
Lengths of cell dipole, quadrupole	16.54 m,		3.64 m
Vertical beamline separation	0.70 m		
Cells per arc, modules per cluster	143,		4
Number dipoles: cell, module, ring	12,	50,	3832
Module tunes: XL, XM, U	3.75,	3.75,	2.25

The eight straight sections are distributed in two clusters of four each, connected by two nearly semicircular arcs. This arrangement gives an oval shape to the machine, see Figure 1, and the geometry, in plan view, has two superperiods. Each arc has 143 FODO cells, each cluster has four modules, and each module includes one straight section.

There are four types of straight sections; the corresponding modules are designated *XL, XM, U,* and *F*. An *XL* or *XM* module contains an experimental, beam-crossing straight section; a *U* module contains a utility straight section; and an *F* module contains a straight section intended for future development as an IR, but initially given the same structure as a utility straight section. Since it is near the injectors and the campus area, the sequence $NCL = U,\ U,\ XL,\ XL$ is called the Near Cluster, while $FCL = F,\ F,\ XM,\ XM$ is called the Far Cluster. With these definitions, the complete SSC lattice, may be written

$$SSC = NCL,\ Arc,\ FCL,\ Arc.$$

In the IRs, the beams are strongly focussed by quadrupole triplets on either side of the IP. The *XL* straight sections are designed for high-luminosity operation. There, the β-value at the IP is $\beta^* = 0.5$ m, and the distance between the IP and the nearest quadrupole is $L^* = 20$ m. The *XM* straight sections provide intermediate luminosities, with $\beta^* = 10$ m and $L^* = 120$ m. Utility straight sections contain injection, beam abort, and rf systems, beam scrapers, and collimators.

Symmetries

The lattice conforms to the following rules. The first concerns the relationship between the two rings. The magnets of one are placed directly above those of the other. The magnets of each vertical pair are physically identical. The members of a pair of *horizontal* dipoles produce *equal* bending, the *vertical* dipoles produce *opposite* bending, and the *quadrupoles* produce *opposite* focusing on the two beams. The quadrupoles and vertical beam-splitting dipoles near the IPs, which are common to both beams, bend and focus the two beams *oppositely.*

The second rule concerns the structure of a cluster module, for each beamline. The beamlines are *antisymmetric* about the center of each straight section: the structure *reflects* about this point. The relationships between the members of the reflected magnet pairs are the same as those between the vertical pairs. Thus a QF on one side of the IP reflects into a QD on the other. The orbit functions β_x, β_y similarly reflect into each other.

Third, each cluster module is matched to the arc cells, and it has a length equal to that of ten cells, horizontal bending of 4 1/6 cells, and phase advance of an odd multiple of $\pi/2$. With this choice of phase, one obtains partial cancellation of the chromatic perturbations arising from large β-value quadrupoles in a pair of identical modules.[3]

A space for correction elements is located on one side of each quadrupole. To preserve antisymmetry and the identity of the two rings, these spaces are symmetric about each straight section center; thus, on passing each straight section, their locations alternate between the upstream and downstream sides of the quadrupoles.

Arc Cells

The arcs consist of regular FODO, 90° phase advance cells. Each 114.25-m-long half-cell contains six 16.54-m, 6.613-T dipoles, and one 3.64-m, 230-T/m quadrupole (effective lengths). The two rings have independent, "one-in-one" magnets in separate cryostats. The separation spaces between magnets are 0.8 m long, and a 6.57-m space is placed on one side of each quadrupole. This space is reserved for a "spool piece", where cryogenic connections and correction-coil packages are located. These include dipole correctors for suppression of orbit distortions, trim quadrupoles to make tune variations of up to ±2 units, and sextupoles for chromaticity correction.

The cell length and phase advance were chosen as follows:[4] For different phases the maximum cell length that gives sufficient dynamic aperture was selected. Then the phase was chosen to minimize cost. Secondary considerations were that grouping of a small number of cells into second order achromats is possible with 60° or 90° cells, and that 90° cells permit use of a superior dispersion suppressor.

Cluster Modules

Every module is 2285 m long and contains 50 horizontally bending dipoles. It consists of a sequence of five blocks:

Half-Cell, Dispersion Suppressor, Straight Section, Dispersion Suppressor, Cell.

The module is matched at both ends to the arc cells.

Only the straight sections differ between modules, apart from the differences in the placement of the correction spaces. The (horizontally) straight sections have the length of 11 half-cells. The horizontal and vertical β-functions are interchanged between the ends of a straight section; they are equal at the center; and the horizontal dispersion η_x is zero throughout. The vertical dispersion η_y is also zero, except within the vertical steps of the IR straight sections.

Dispersion Suppressors

A dispersion suppressor consists of two cells, each having three-fourths the length, two-thirds the bending, and the same phase advance as a normal cell. This combination causes the proper dispersion of these cells to be half that of normal cells, while the actual dispersion makes a cosine-wave oscillation through the suppressor, from the cell proper value at one end to zero at the other end. A suppressor maps the β-functions unchanged from the cells to the ends of the straight sections, providing favorable initial conditions for the IR optics. The suppressor magnets are on the main bus; the dipoles are the same as those in the cells, the quadrupoles are longer.

Utility and Future IR Modules

A utility module *U* is shown in Figure 2. Injection and rf equipment are placed in the 235-m outer drift spaces, and beam abort is done in the 638-m center section. The entire straight section is non-dispersive, which is convenient for these functions. The two beamlines do not cross in utility straights, and the tuning is not changed during the operating cycle. The "future" IR modules *F* have identical lattices to those of the utility modules.

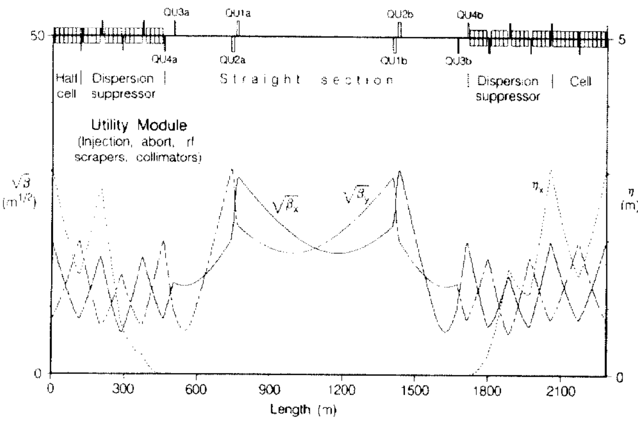

Fig. 2. Utility Module.

Experimental IR Modules

The two proton beams collide and cross at the center of each experimental straight section. The XL and XM modules have the same qualitative structure, so they will be described together.

An IR straight section has the following functions: the two beams must be made to cross vertically at the IP, the vertical dispersion introduced by the vertical bends must be removed, and the β-functions must be matched from their design values at the IP to the cell values that obtain at the ends of the straight section. An XL low-beta module is shown in Figure 3. The beams have waists with small, equal β_x and β_y values and zero dispersion at the IP, where they cross at very small angles, up to 150 μrad. These crossing angles are so small that for design purposes they can be ignored, and one assumes colinear beams in the central IR region. Proceeding away from the IP, the beams pass through a drift space of length L^* ; the triplet Q1, Q2, Q3; the vertical separation and dispersion matching region; and the quadrupoles Q4, Q5, Q6.

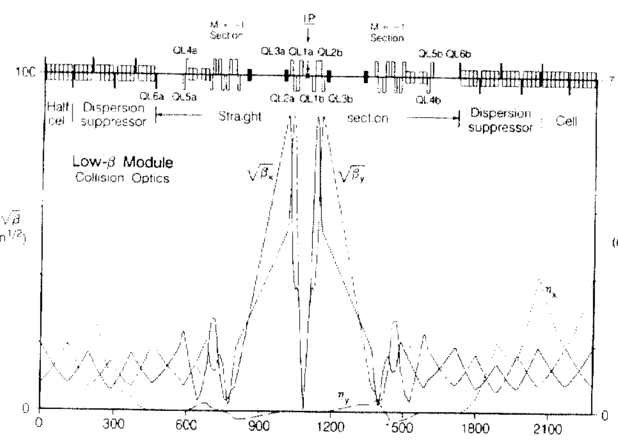

Fig. 3. Low-β Module, Collision Optics.

β-Function Matching

The β-function matching between the IP and the cells is done with the quadrupoles Q1—Q6. The β-functions rise rapidly from their small values at the IP to their peak values in the first triplet, which focus the beams gradually to the last triplet, which then matches the β-functions to the proper cell values.

During injection the β-functions at the IP are tuned to relatively high values, 8 m and 60 m in XL and XM respectively since the large β-functions values in the first triplet that obtain during collision could not be tolerated during injection. The tuning adjustment from the injection to the experimental optics consists of progressively weakening Q5 and strengthening Q6, with continuous small changes in Q1—Q4. The maximum gradient of the matching quadrupoles is 231 T/m.

Vertical Orbit Translation and Dispersion Matching

Between Q3 and Q4 each beam is given a parallel, vertical translation of 35 cm, done in two steps of 17.5 cm each. The first step after the IP begins with a set of splitter magnets common to both beams, and ends with a set of separated magnets. Between the two steps is a hotizontal region, with two 90° FODO cells without bends. This region has a transfer matrix $M = -1$, which changes the sign of η_y but is transparent to the β-functions. The second step then restores η_y to zero value.

Optical Properties

Ideally, adjacent IRs should be tuned to the same β^* values; however, it is feasible to operate the SSC flexibly. This is shown by the chromatic behaviour in three operating cases:

1. Collision: Four IRs with β^* at experimental values
2. Intermediate: Three β^* at their experimental values, one in an XL at the injection value
3. Injection: All β^* at their injection values

The tune dependence on momentum deviation $\delta = \Delta E/E$ for these three cases is shown in Figure 4. This behaviour, and that of β^* at the IPs, is quite acceptable within the range $|\delta| < 10^{-3}$.

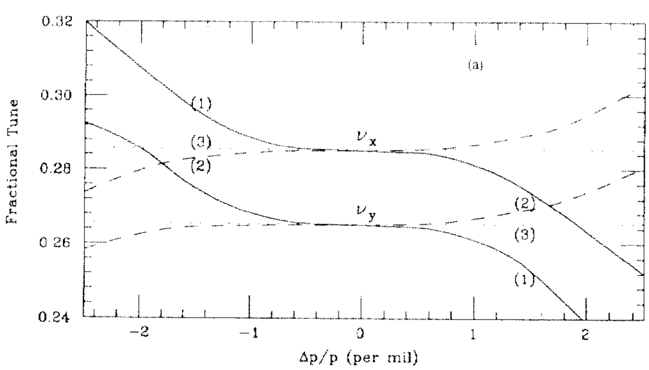

Fig. 4. Momentum Dependence of the Tunes.

Conclusions

An SSC lattice has been designed; characterized by simplicity, modularity, compactness, good orbit quality, and convenient arrangement of machine and experimental facilities.

References

1. A. A. Garren, "Lattice of the SSC," *Proceedings of the 13th International Conference on High Energy Accelerators*, Novosibirsk, USSR, (August 1986) **SSC-81**.
2. A. A. Garren and D. E. Johnson, "The 90° (September 1987) SSC Lattice," **SSC-146**, 1987
3. A. Garren, *et al.*, "On Improving the Chromatic Effects of Storage Rings with Antisymmetric Insertions," *IEEE Trans. Nucl. Sci.* **NS–30** (1983).
4. "Optimization of the Cell Lattice Parameters for the SSC," **SSC-SR-1024**, (1986).