IEEE Transactions on Nuclear Science, Vol. NS-32, No. 5, October 1985

SSC TEST LATTICE DESIGNS*

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Simple test lattices for a 20 TeV superconducting super collider have been designed based on each of the major dipole designs, 3, 5, 6, and 6.5 Tesla. These lattices have been made as nearly identical as possible. The reason for different lattices is to be able to evaluate equally the different magnet designs, with associated multiple distributions and persistent current errors, through analytical and tracking programs without the complications of different lattice designs. It should be noted that while these designs are typical of a 20 TeV SSC, they are meant only for study and do not represent a machine which would be built. Thus, they do not have crossing magnets or utility insertions. However special phase shifting sections called Phase Trombones are included, a feature not present in most of the previous SSC lattice designs [1-5].

Superperiod Structure

The test lattices have six superperiods, each containing four components: A, D, T, X and their antisymmetric reflections $\tilde{A}, \tilde{D}, \tilde{T}, \tilde{X}$. Antisymmetric reflection is mirror reflection and reversal in sign of the gradients. The complete superperiod S is

$$S = \tilde{A}\ A\ D\ T\ X\ \tilde{X}\ \tilde{T}\ \tilde{D}$$

The superperiod components are:

$\tilde{A}$ A - the arc of regular FODO bending cells

D, $\tilde{D}$ - dispersion suppressors

T, $\tilde{T}$ - phase shifting 'trombones'

X $\tilde{X}$ - the low beta crossing insertion

The superperiod, shown in Fig. 1, has two antisymmetric reflection points, one at the arc center and the other at the center of the crossing insertion.

Motivation for Antisymmetry: The two proton rings are parallel except in the vicinity of the collision points, where the beams cross at a small angle, pass through common quadrupole triplets, are split by common dipoles, and are bent back to their separate beam lines. The common quadrupoles have equal and opposite focussing effects on the two beams, so it is important that the separated quadrupoles act in the same way.

If the focussing on each beam were symmetric about the collision or interaction point (I.P.), then the beta functions and the phases of the insertion would be different for the two beams, the periodicies would be lower and the sextupole corrections made more complicated. Hence, the lattices have antisymmetry about the crossing points. They are also antisymmetric about the arc centers.

Arcs: There are Narc = n±1/2 cells in the arc $\tilde{A}$ A, where n is a multiple of 6 or 4 for 60 or 90 degree cells respectively. The chromaticity sextupoles fill an integral number of betatron wavelengths, which partially cancels their geometric perturbations.

Regular Cells: Fig. 2 shows a regular arc cell. The bending magnets in each half-cell are represented as a single dipole slot. These can be subdivided into subintervals for insertion of thin lens multipoles in the tracking studies. The slots are centered between the quadrupoles, and two sextupoles are placed in one half-cell with none in the next one, following a suggestion by A. Chao. These simplifications permit antisymmetry about the arc center without a discontinuity in either the bending or the sextupoles.

Dispersion Suppressors: The dispersion suppressors D and $\tilde{D}$ border the arc (Fig.1). Each consists of two cells with a total bending angle equal to that of one cell. The cell and quadrupole lengths and gradients are the same as those of regular cells. In the real collider the adjacent suppressors on the two beams are D and $\tilde{D}$, so that the dipoles are adjacent for the two beamlines.

If the two cells of D as one approaches the I.P. are called C1 and C2, dipoles of length (1-a)*Lb and a*Lb are placed in the half-cells of C1 and C2 respectivily, where Lb is the length of a cell dipole. It can be shown that the dispersion and its slope are brought to zero if

$$a = 1/[2(1-\cos\mu)],$$

where μ is the phase advance per cell. Thus the bending in C1 and C2 is 0 and 1 for 60 degree cells and 1/2 and 1/2 for 90 degree cells, compared to a regular cell. The centers of gravity of the dipoles must be placed at the same locations in the half-cells of C1 and C2 as they have in the normal cells. These results have been given previously by R. Helm [6].

Fig. 3 shows the dispersion suppressor of a 60 degree test lattice.

Since the betatron focussing of the suppressors is like that of regular cells, the cell beta values are mapped from their entrance to their exit.

Phase Trombones: The phase trombone T, shown in Fig. 4, closely resembles three regular cells without dipoles. The quadrupoles are powered symmetrically about the center and adjusted to map the normal cell beta functions at its entrance to a waist at its center, so that the entrance values are repeated at the end. In addition, the horizontal and vertical phase advances are constrained to produce the desired tunes.

The trombones permit one to change β^*, the beta function at the I.P., from one to several hundred meters while keeping the tunes constant, or to change the tunes by several units at fixed β^*. Since the horizontal and vertical phase advances through T and $\tilde{T}$ are interchanged, together they move the tunes along the diagonal. This is suitable for compensation for changes in β^*, since the antisymmetry of the crossing insertion $X\tilde{X}$ assures that it will produce equal phases. To split the tunes, the circuits of T and $\tilde{T}$ must be controlled independently.

Crossing Insertion: The left half X of the crossing insertion $X\tilde{X}$ is shown in Fig. 5. At its entrance the beta functions are those of a regular cell in the center of a QF quadrupole, except that the dispersion and its slope are zero. The insertion, 500 meters long, is nearly identical to that of the SSC Reference Design A [4], except that the crossing magnets B+ and B-, located at the ends of the space between Q3 and Q4 are left out. The six quadrupoles are adjusted to produce a waist with the required value of β^* at the I.P., and to adjust the phases. The horizontal and vertical beta values at the I.P. must be the same so that the right side of the insertion, $\tilde{X}$, will produce the same beta functions at its right end as occur at the center of the

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QD quadrupole of a normal cell. In the experimental configuration, $\beta^*=1$ m, and the total phase advance of the insertion is 2π.

Number of Cells and Tune Values: The approximate number of cells in an arc, Narc, is determined by the magnetic field. However its exact value is quantized by the considerations discussed previously in the paragraph on arcs, by choosing to set the phase advance of the low-beta insertion equal to 2π (the value required for the Reference Designs), by setting the phase of the trombone close to that of three normal cells (in the standard optics) to minimize its chromatic contribution, and choosing tune values of $6k + 2.3$ or $6k + 4.3$, i.e., between one and two units from a half-integer structure resonance.

Specific Description of the Lattices

There are eight lattices, corresponding to four magnetic fields, 6.5, 6, 5, and 3 Tesla, and two cell phase advances, 60 and 90 degrees.

Cells: The length L of the half-cell was chosen to make $L\Theta=0.8$, where Θ is the bending angle in radians per half cell. This rule equalizes the dispersion (for a given phase), so that a given momentum deviation will always cause the protons to see the same strength of multipole fields.

The average magnetic field of the dipole slots was chosen to give the same bend angle as would eight separate dipoles with 0.5 meter separation at the nominal fields (except for the C lattices, which have ten dipoles).

The quadrupole gradient in the cells was set between 130 and 150 T/m. However the gradients near the crossings were set as high as 300 T/m to reduce the maximum beta values.

Each half-cell contains two drift spaces with total length of about 10 meters for sextupoles, correction elements, etc.

Parameters: The eight test lattices were designed, following the above prescriptions, using the SYNCH program. Their principal parameters are given in Table I.

Chromatic Effects

The variations of the tunes and the beta values at the I.P. with momentum deviation have been explored using the programs SYNCH and DIMAT, which give good agreement. Fig. 6 shows the tune variations of the eight lattices for the standard scheme having an F and a D sextupole in each cell. These variations appear to be acceptable over the expected operating range of $dp/p=\pm0.004$.

A simple non-interleaved scheme, in which two F sextupoles are placed 180 degrees apart in phase, followed by two D sextupoles also separated by 180 degrees, was also investigated. Fig. 7 shows the tune variation for two of the lattices with the non-interleaved scheme. The flat portion of the tune curve is extended, particularly for the 3 tesla lattices. This is probably due to the larger number of cells for these lattices, which prevents the sextupole strengths from becoming too high.

Several of the lattices have been tracked with the interleaved scheme, and one with the non-interleaved one. For this case at least, the latter scheme gives a much larger dynamic aperture than the former [7].

Conclusions

A set of SSC Test Lattices designed with varying magnetic fields and betatron phase advances has been constructed, and shown to be useful for studies of chromatic correction and dynamic aperture. This paper is a condensed version of SSC-19, available from the SSC Design Center.

Acknowledgments

The broad concepts that influenced the design of these lattices were set by the members of the Test Lattice Group of the SSC Aperture Task Force and by the participants in a lattice meeting at BNL in December 1984. We are happy to acknowledge their contributions. We are also very grateful to M.J. Syphers for editorial assistance.

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Table I --- Parameters of the Test Lattices

Case	Phase deg	Field tesla	Bslot tesla	Gradient tesla/m	Lcell m	Lslot m	Lquad m	Lcorr m	Ncells (equiv)	Narc	Circumference km	Tune	Beta (cell) m	Eta (cell) m	Beta (max) m	Chromaticity
A1	60	6.469	6.198	135.7	200	83.5	5.0	5.75	405	65.5	93.60	82.29	345	3.87	4627	-200
A2	90	6.566	6.291	138.0	200	83.5	7.0	4.75	399	64.5	92.40	118.27	339	2.13	4183	-260
D1	60	5.994	5.748	135.7	200	85.0	5.0	5.00	429	69.5	98.40	85.35	345	3.66	3910	-205
D2	90	6.006	5.751	134.6	205	86.0	7.0	4.75	423	68.5	99.56	124.35	347	2.06	3900	-267
B1	60	5.096	4.910	136.6	220	95.5	4.5	5.00	447	72.5	111.90	88.30	380	3.86	4415	-206
B2	90	5.096	4.910	145.6	220	95.5	6.0	4.25	447	72.5	111.90	130.29	373	2.09	4187	-275
C1	60	3.054	2.948	129.8	290	129.5	3.5	6.00	549	89.5	181.49	106.29	512	4.19	4625	-227
C2	90	2.989	2.885	129.0	290	129.5	5.0	5.25	561	91.5	181.49	157.29	503	2.27	4454	-308

Fig. 1 Superperiod Structure

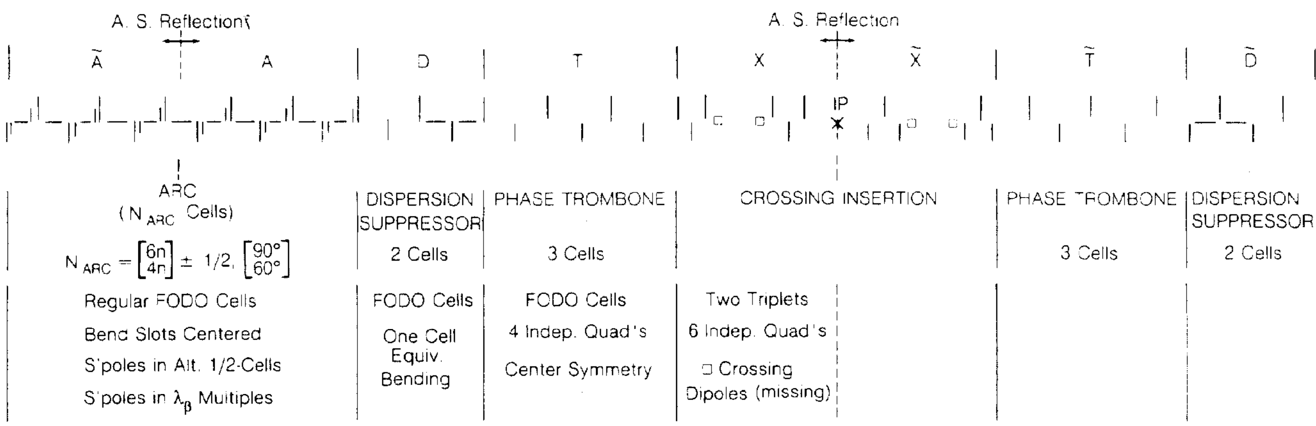


Fig. 2 Regular Cell

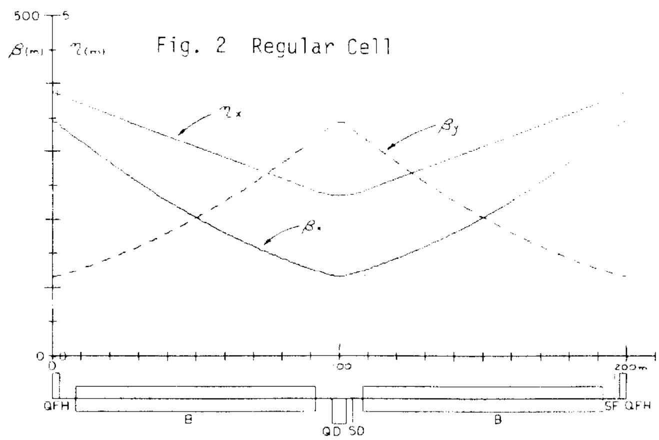


Fig. 3 Dispersion Suppressor for 60° Cell Lattice

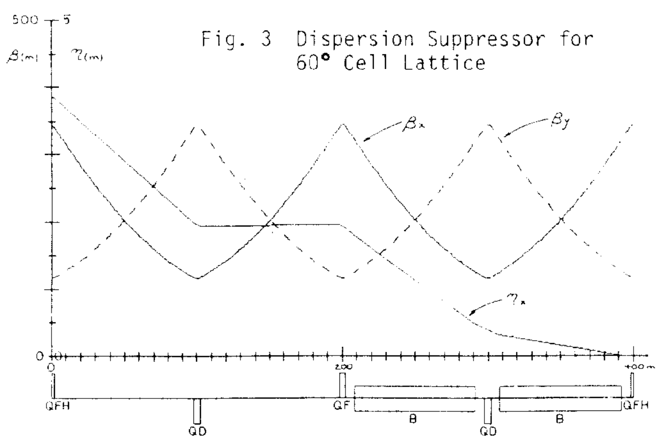


Fig. 4 Phase Trombone

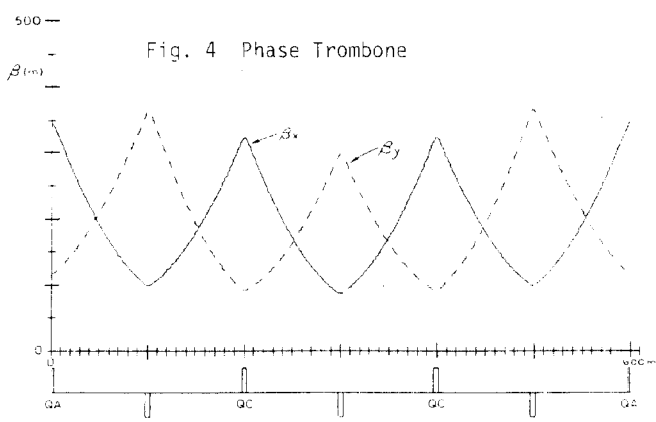
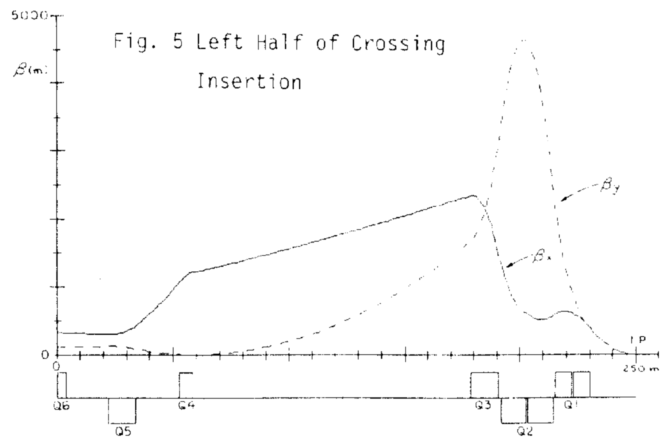


Fig. 5 Left Half of Crossing Insertion



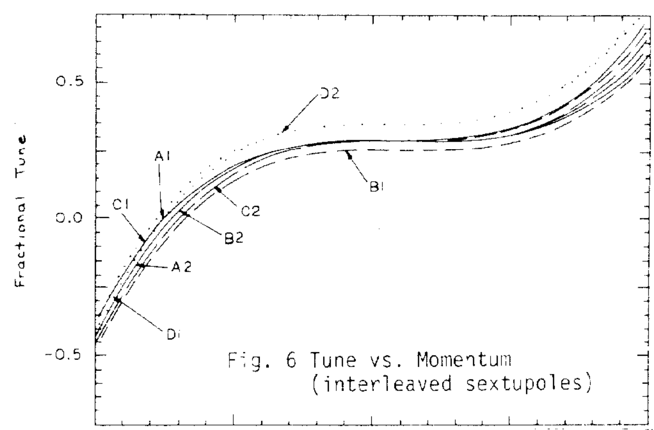


Fig. 6 Tune vs. Momentum (interleaved sextupoles)

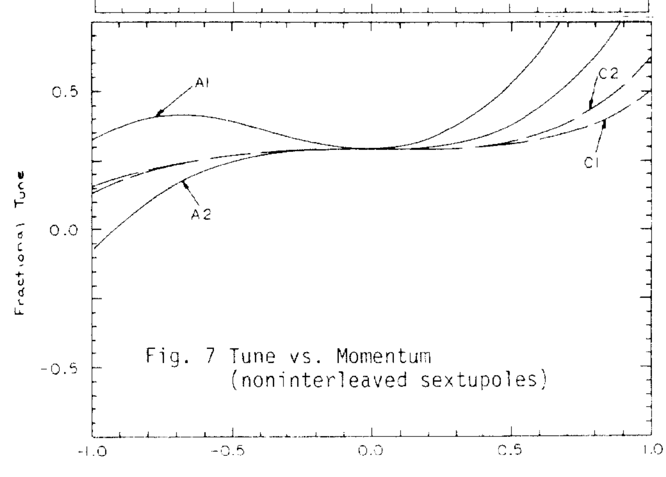


Fig. 7 Tune vs. Momentum (noninterleaved sextupoles)