SSCL-Preprint-349

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May 1993
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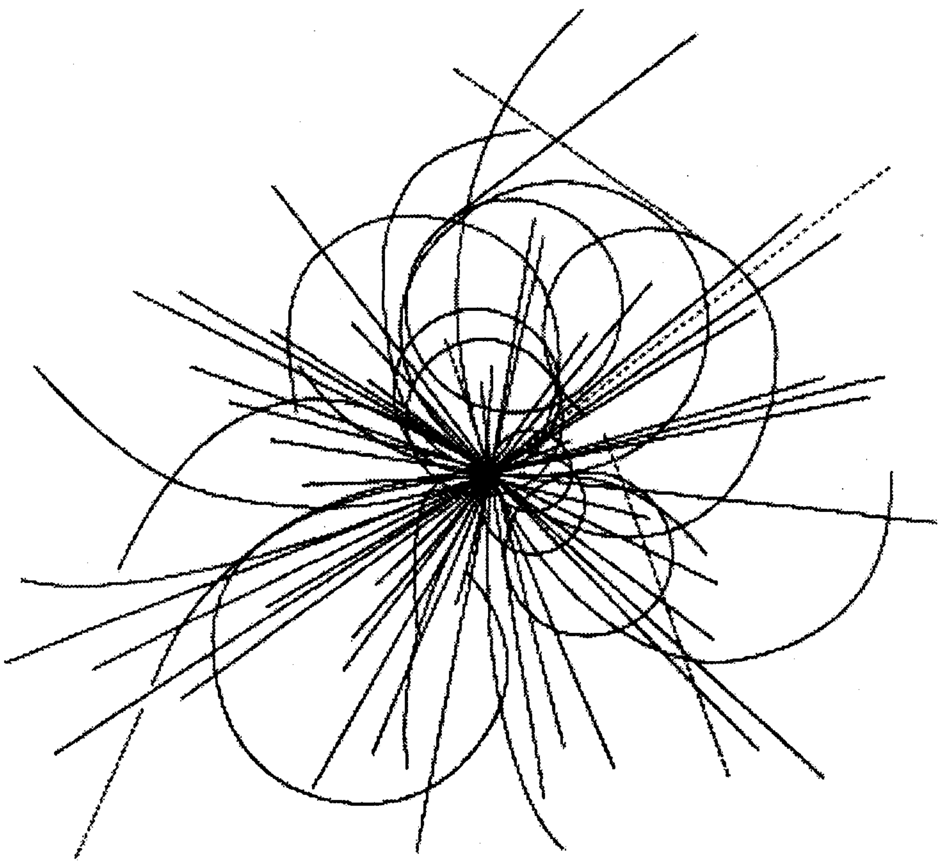

Superconducting Super Collider Laboratory

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May 1993

*To be presented at the 1993 IEEE Particle Accelerator Conference on May 17–20, Washington, D.C.

†Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

Modification of the Short Straight Sections of the High Energy Booster of the SSC*

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Abstract

The tracking analysis with the High Energy Booster (HEB) of the Superconducting Super Collider (SSC) indicated that the machine dynamic aperture for the current lattice (Rev 0 lattice) was limited by the quadrupoles in the short straight sections. A new lattice, Rev 1, with modified short straight sections was proposed. The results of tracking the two lattices up to 5×10^5 turns (20 seconds at the injection energy) with various random seeds are presented in this paper. The new lattice has increased dynamic aperture from ~7 mm to ~8 mm, increases the abort kicker effectiveness, and eliminates one family (length) of main quadrupoles.

The code DIMAD [1] was used for matching the new short straight sections to the ring. The code TEAPOT [2] was used for the short term tracking and to create a machine file, zfile, which could in turn be used to generate a one-turn map with the use of ZLIB [3] for fast long-term tracking using a symplectic one-turn map tracking program ZIMAPTRK [4].

I. INTRODUCTION

The HEB lattice is designed to operate in the energy range of 0.2-2 TeV. The HEB is a bipolar machine, that alternately injects beam to the top and bottom collider ring. A geometry compatible with easy injection from a monopolar Medium Energy Booster (MEB) is required. The basic overall design consists of two nearly semicircular arcs connected by long straight sections. One long straight section is used for fast ejection of the beams in opposite directions for transfer to the two collider rings as well as for the resonantly-extracted test beams; in addition, it contains the RF acceleration system. The other long straight section contains the electrostatic septa for extraction of the test beams (Future requirement). The two semicircular arcs each contain two short straight sections. The two in the south are used for beam injection from the MEB, and the two in the north arc are used for the two beam aborts. The HEB geometry is shown in Figure 1.

The HEB normal operation cycle begins at the injection of proton bunches from the MEB at 200 GeV, which lasts about 20 seconds, or 5.5×10^5 turns. Simulation of Rev 0 lattice up to 10^5 turns indicated that the quadrupoles in the short straight sections dominated the nonlinearities of the HEB ring and limited its dynamic aperture [5]. The dynamic aperture can be increased from 7 mm to 9 mm when the multipole errors are set to zero in the short straight section quadrupoles. Further simulation work, using various random number seeds, even failed to find the closed orbit correctly after the multipole errors of the quadrupoles in short straight sections were included. This motivated us to change the Rev 0 lattice.

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Efforts were exerted to decrease the beta-functions in short straight sections and shorten the lengths of the quadrupoles in same region, such that the $\Sigma k\beta l$ would be reduced. Since the civil design work for the tunnel already started, we decided to limit any geometrical changes to the short straight sections. The new Rev 1 lattice keeps the length of each short straight section unchanged, but decreased the central clear drift region from 112.7 m to 102.5 m. The 102.5 m was necessary to allow MEB to HEB injection within the central drift area. On the other hand, the abort line located in the north short straight sections preferred higher vertical β-functions to increase the abort kicker effectiveness. Rev 1 lattice achieved this, which seems to be contrary to the goal of reducing the $\Sigma k\beta l$. Since the quadrupoles in short straight sections are shortened significantly, we are able to replace one family of quadrupoles with the main arc quadrupole supplemented by adding corrector trim quadrupoles. This should reduce the overall cost of the HEB.

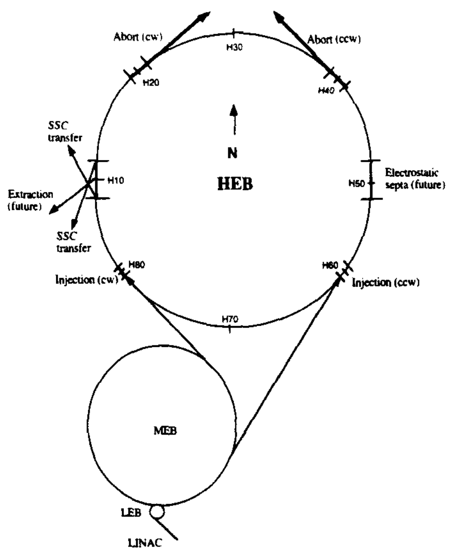

Figure 1. HEB ring layout.

II. REV 1 LATTICE

Figure 2 shows the schematic view of half short straight section of Rev 0 and Rev 1 lattices. First of all, by separating the doublet quadrupoles, Qs2 and Qs3, we succeeded in reducing the lengths of each quadrupole, as well as the β-functions in short straight sections. Spool 1 has been moved in between Qs2 and Qs3 in north short straight sections (H20, H40). This allowed the abort kickers to be shifted closer to the quadrupole and in a region with higher vertical β functions; This increased the kicker effectiveness. By separating Qs2 and Qs3 by the exact slot length of the spool piece plus standard interconnect, the need for a special length empty cryostat is eliminated.

For the injection straight sections (H60, H80) spool 2 has been moved to between Qs2 and Qs3. By doing this, enough clear drift is provided in the center of the straight section to accommodate the injection beamlines from the MEB.

Fitting showed that the Qs1 length needed was close to the main quadrupole effective magnetic length of 1.6 m. In order to use the main quadrupole for Qs1 and eliminate one family of quadrupoles, we used two correction quadrupoles to compensate for the slight length difference. Fitting was performed using the code DIMAD.

The β and η functions of Rev 0 and Rev 1 short straight sections are shown in Figure 3 and Figure 4. The $\Sigma k\beta l$ of the two short straight sections are presented in Table 1.

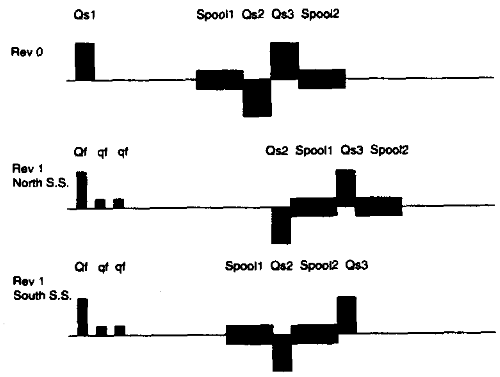

Figure 2. Comparison of the short straight section in Rev 0 and Rev 1 lattices.

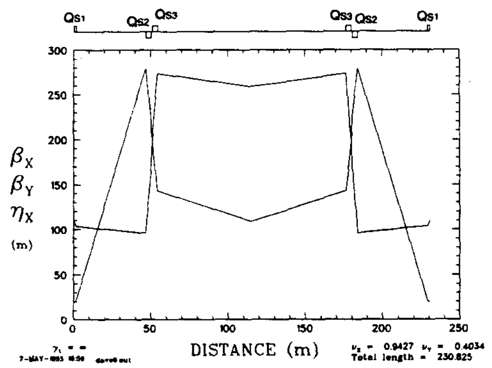

Figure 3. β and η functions of Rev 0 short straight section.

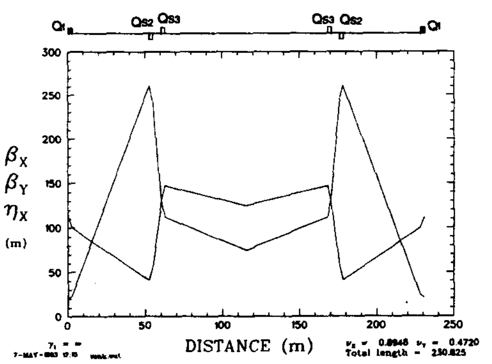

Figure 4. β and η functions of Rev 1 short straight section.

Table 1
The Sum of k*l*β in short straight sections

Quads	k(m^{-2})	l (m)	β_x (m)	β_y (m)	$\|k\| l\beta_x$	$\|k\| l\beta_y$
Rev 0						
Qs 1	0.0276	2.2578	103.8	20.4	6.48	1.27
Qs 2	–0.0276	3.3465	164.3	228.2	15.20	21.11
Qs 3	0.0276	3.3465	273.4	143.0	25.29	13.23
Total					46.97	35.61
Rev 1						
Qf	0.0276	1.6	113.2	19.5	5.00	0.86
qf	0.009	0.26	107.3	20.8	0.25	0.05
qf	0.010	0.26	105.6	21.2	0.27	0.06
Qs2	–0.0276	2.228	57.0	257.9	3.51	15.86
Qs3	0.0276	2.228	149.0	120.3	9.16	7.40
Total					18.19	24.23

III. LONG TERM TRACKING

To perform long term tracking we use TEAPOT to convert each magnet into one or more thin lenses and concatenate them to a machine file. All misalignment and multipole errors are included, and then the correction scheme is used to compensate for errors. This machine file is then used to get a one-turn map by using a ZLIB related program ZMAP. Finally, the symplectic one-turn map tracking code ZIMAPTRK is used for fast long-term tracking of up to 5×10^5 turns to determine the dynamic aperture.

Rev 1 lattice has a $\pm 3\%$ β-function mismatch in arc cells in order to maintain 102.5 m clear space at the middle of the south short straight section. This mismatch is negligible compared with greater mismatch introduced by realistic nonlinearities. The misalignment of magnets and Beam Position Monitors (BPM), and multipole errors of magnets we are using for simulation are shown in Table 2 and Table 3 separately. For correction quadrupoles each multipole error of main quadrupoles multiplied by 10 is used. After correction the maximum deviation of closed orbit is less than 1 mm, the chromaticity is fit to zero, the coupling effect is minimized, and the machine is tuned to the nominal tunes (ν_x = 39.425, ν_y = 38.415).

The final results of the dynamic apertures are shown in Table 4. Rev 0 lattice failed to get a closed orbit with two of nine random number generation seeds. A mini study was conducted on the Rev 1 lattice by doubling each multipole error of the quadrupole in short straight section only and of all magnets with the seed number 7. The closed orbit exists in both cases, and the dynamic aperture is 7.5 mm (double error of quadrupole in short straight sections only) or 6.0 mm (double error of all magnets) respectively. This indicated that the quadrupoles in short straight sections are no longer dominating the nonlinearities of the HEB ring and the Rev 1 lattice is more reliable.

Table 2
HEB Magnet and BPM Alignment Tolerances

Element	Component	Tolerance
Dipole	Horizontal σ_x (mm)	1.1
	Vertical σ_y (mm)	1.1
	Field Angle σ_Θ (mrad)	1.01
	Sigma b_0	0.001
Quadrupole	Horizontal σ_x (mm)	0.4
	Vertical σ_y (mm)	0.4
	Field Angle σ_Θ (mrad)	0.56
BPM	Horizontal σ_x (mm)	0.3
	Vertical σ_y (mm)	0.3

Table 3
Limit of HEB Magnet Multipoles

Multipole	Dipole Random RMS ($\times 10^{-4}$ @ 1 cm)	Quadrupole Random RMS ($\times 10^{-4}$ @ 1 cm)	Dipole Systematic ($\times 10^{-4}$ @ 1 cm)	Quadrupole Systematic ($\times 10^{-4}$ @ 1 cm)
a1 / b1	1.25 / 0.50	4.80 / 0.00	0.04 / 0.04	2.00 / 0.00
a2 / b2	0.35 / 1.15	1.77 / 1.77	0.032 / –2.00	0.184 / 0.184
a3 / b3	0.32 / 0.16	0.81 / 0.81	0.026 / 0.026	0.085 / 0.085
a4 / b4	0.05 / 0.22	0.22 / 0.22	0.02 / 0.08	0.078 / 0.078
a5 / b5	0.05 / 0.02	0.206 / 0.103	0.02 / 0.02	0.072 / –0.57
a6 / b6	0.02 / 0.02	0.032 / 0.032	0.02 / –0.02	0.033 / 0.033
a7 / b7	0.02 / 0.02	0.029 / 0.029	0.02 / 0.02	0.03 / 0.03
a8 / b8	0.02 / 0.02	0.02 / 0.02	0.02 / 0.02	0.02 / 0.02

Table 4
HEB Dynamic Aperture at 500,000 Turns

Seed Number	Rev 0 (mm)	Rev 1 (mm)
1	6.7	8.0
2	7.0	8.3
3	6.9	7.6
4	7.5	8.0
5	7.7	9.1
6	7.3	8.7
7	failed	8.1
8	failed	7.7
9	7.4	9.1
Average	(7.2)	8.3

IV. SUMMARY

ZIMAPTRK succeeded in long term tracking of the HEB up to the million turn level. It will be used for tracking the HEB with ramping of the energy in the future.

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