Design Description of the SSC High Energy Booster

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Abstract

A description of the design and operation of the High Energy Booster is presented below. This includes an overview of the general geometry of the ring followed by details of the various lattice components. Aspects of the injection, abort, extraction, and resonant extraction processes are also presented. The rf system and some plans for the operational cycles are also given.

Global Structure

The HEB lattice is designed to operate in the energy range of 200 – 2000 GeV. The design was determined primarily by requirements of the top energy. In order to inject the dual beams into one collider utility section, the HEB must operate in a bipolar manner. A clean resonant-extraction system to produce slow-spill protons for the test beams is needed. In addition, a geometry compatible with easy injection from a monopolar 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 both 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. The two semicircular arcs each contain two short straight sections. The two in the south arc 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 Fig. 1 and the general parameters of the HEB are listed in Table 1. The lattice functions and the magnet layout for half of the HEB ring are shown in Fig. 2.

Several of the overall parameters of the HEB design were determined by requirements of the dipole magnets. The maximum dipole field was chosen to be slightly less than the collider's 6.6 T at the standard operating temperature of 4.35° K. For a top energy of 2 TeV, an injection energy from the MEB of 200 GeV then gives a magnetic range of 10:1, in keeping with the collider design. The need for resonant extraction further defined the dipole aperture, and this aperture, along with the dynamic range, led to the present HEB cycle times. The operating cycles for the HEB are determined by the heat-load capacity of the cryogenic system. Removal of the heat generated by hysteresis and AC losses in the magnets during the injection cycle into the collider requires approximately one-quarter of the refrigeration needed for the collider at top energy. The test-beam cycle uses the same ramp rates and lengthens the flat top for the extraction process. The HEB must be capable of bipolar operation. All of the design choices affected by this requirement, such as injections, aborts, and transfers, have been made compatible with bipolar operational. Also, the basic lattice design was chosen to be symmetric, so the apertures explored in each magnet by the beam will be the same for both directions of operation. The operation of the HEB in a bipolar manner should not present a problem.

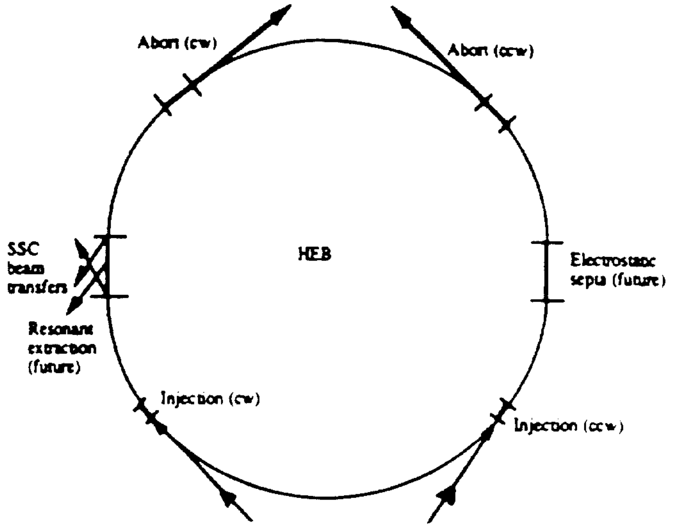

Figure 1 - HEB Ring Layout

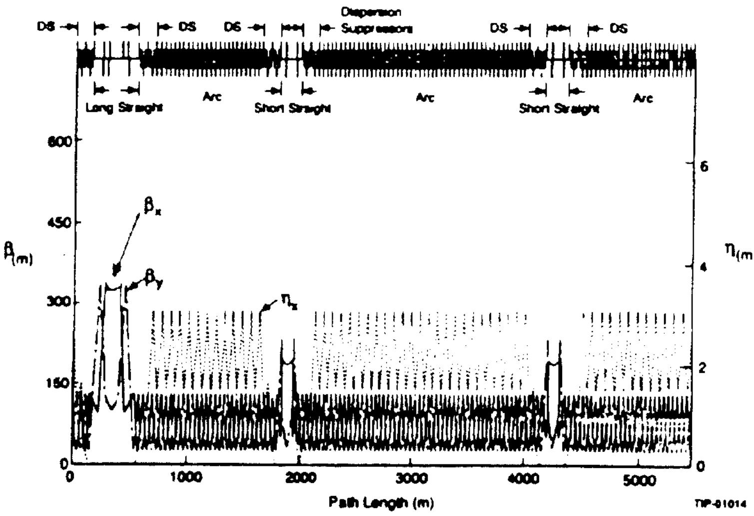

Figure 2 - Lattice Functions for One-half HEB

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All of the magnets will be reversible, as will the beam instrumentation. Preliminary magnet tests over a bipolar ramp give good agreement with expected results and indicate no difficulty with bipolar operations.[1]

Arcs

The arcs of the HEB consist of normal FODO cells, with two dispersion suppressing cells on either end. The cells have a phase advance of 90° and a half-cell length of 38.065m. Each normal half cell contains two, 15.18m, 6.4 T dipoles (at 2 TeV/c) separated by 0.65 m, one 1.20 m, 208.5 T/m quadrupole, and a 4.575 m correction spool slot length. The dispersion suppressing cells are the same except that each half cell contains only one dipole. Layouts of the HEB half cell and the dispersion suppression cells are shown in Fig. 3.

Table I – Parameters of the HEB Lattice

Momentum : Inj., Ext. (TeV/c)	0.2 / 2
Circumference (km)	10.800
Operational mode	Bipolar
Lattice type	FODO
Structure: two superperiods	
Two long-straight sections: (m)	389.85
Extraction, Test beams, rf	
Four short-straight sections: (m)	222.925
Injection, Aborts	
ϵ_T (rms) (mm-mrad)	0.8π
ϵ_L (rms) (eV-sec)	0.035π
Harmonic number	2160
Bunch spacing (m)	5
Protons per bunch	1×10^{10}
Half-cell length (m)	38.065
Cell phase advance	90°
Betatron tunes ν_x, ν_y	34.425 / 33.415
Natural chromaticities ξ_x, ξ_y	-45.3 / -45.6
Momentum compaction	0.0011529
$\beta_{\max}$, $\beta_{\min}$ in arcs (m)	129 / 23
$\eta_{\max}$, $\eta_{\min}$ in arcs (m)	3.00 / 1.44
$\beta_{\max}$ in straight sections (H, V) (m)	370 / 345
Number of dipoles/half cell	2
Number of dipoles	432
Number of quadrupoles	278
Cell dipole, quad lengths (eff) (m)	15.17 / 1.20
Magnetic field, gradient (max) (T, T/m)	6.39 / 206
Average, magnetic radius (km)	1.72 / 1.07
Number of sextupole families	2
Number of sextupoles	192
Sextupole strength (max) (T/m)	263
Rf frequency (MHz)	60.0
Rf voltage (MV)	1.6
ϕ_S	30°
Cycle time: bipolar transfer (min)	8.6

Long-straight Sections

The long-straight sections have been designed allow horizontal extraction of beams in each direction for the transfer to the collider, and to allow for resonantly-extracted test beams.

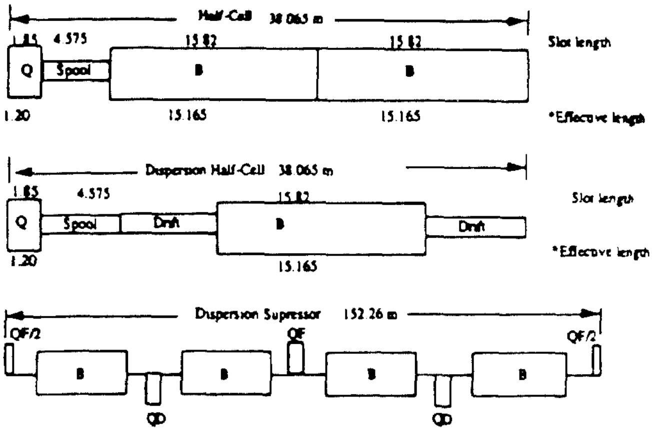

Figure 3 – Cell structure

Each long straight section consists of a four half-cell dispersion suppressor on either end, a central straight section of some 115 m, in which the horizontal beta function has been made very large to accommodate a clean resonant extraction, and an 80 m long straight on either end with a total longitudinal separation of 390 m, the length required to match transfer lines into one utility section in the Collider. The wast straight section is used for the ejection of beam for transfer into the collider in each direction and for the extraction channel for the resonantly-extracted test beams. Horizontal kickers for the transfer extraction are put into missing magnet locations in the dispersion suppressors. The northern end of the wast long-straight section also contains the rf system.

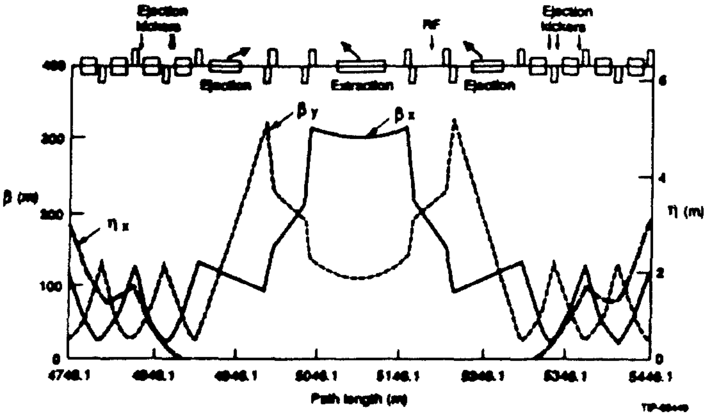

Figure 4 – Lattice functions for the long-straight sections

The central portion of the east straight section will contain a conventional magnet dogleg bump across the central portion of the straight into which will be put the electrostatic septa required for the half-integer resonant-extraction process.

The structure and lattice functions for the long-straight section are illustrated in Fig. 4. Also indicated are the ejection, extraction, and rf component locations in the west straight section.

Short-straight Sections

The short-straight sections were designed to allow easy injection from the MEB and to provide for beam abort systems in both directions. The structure and lattice functions of the short-straight sections are shown in Fig. 5. In the straight sections on the south side of the ring, the beam from the MEB is injected vertically into the downstream part of the section, in a 50 m long region. The injection kickers are placed in the downstream free spaces within the dispersion suppressors. The beam aborts are places in the central free space of the straight sections on the north end of the ring. This region is slightly more that 100 m long and will contain conventional dipoles, lambertsons, and C-magnets arranged to produce a dogleg configuration for the abort.

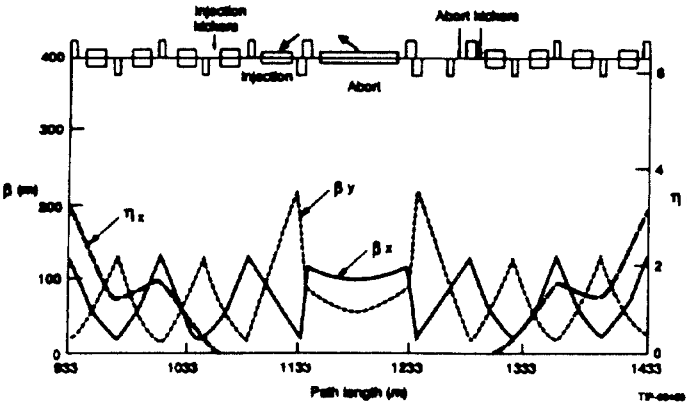

Figure 5 - Lattice functions for the short-straight sections

In order to inject into the two straight sections, one in either direction, from the MEB with little horizontal bending in the beam transfer lines, the symmetry of the HEB has been distorted as shown in Fig. 1. Instead of having each arc divided into three equal 60° angles, the division is 46.7°, 86.6°, 46.7°.

The Injection System

Injection into the HEB occurs in the downstream section of the short-straight sections. The beam is brought down toward the HEB and injected into the machine through a 5 m C-magnet followed by three, 5 m lambertson magnets. The beam at the entrance to the first C-magnet is above the machine axis by approximately 50 cm, missing the cryostat of the upstream quadrupole. The lambertsons and C-magnets run at 1.0 and 1.2 T, respectfully. After being directed into the machine, the injected beam is kicked onto the closed orbit with four fast kicker magnets placed at the downstream end of the first half cell in the dispersion-suppressing section following the straight section.

Operational Cycles

The HEB will operate in a bipolar cycle in order to fill both collider rings. Two options exist for this operation - fill one collider ring, reverse the HEB fields, and then fill the other collider ring, or inject beam alternately into one ring and then the other. The first mode was initially proposed. This led to concerns that the time to reverse the magnetic fields and stabilize the persistent-current effects could not be determined *a priori* and might lead to a long collider filling time. It was decided to operate the HEB following a bipolar supercycle and alternate injection into the two collider rings. This requires that both beams be treated equally and that both exist equally long in the collider injection fields, but it does guarantee that the filling cycle does not contain an unknown, possibly long amount of time in order to switch from one direction of operation to the other. The HEB supercycle is shown in Fig. 6.

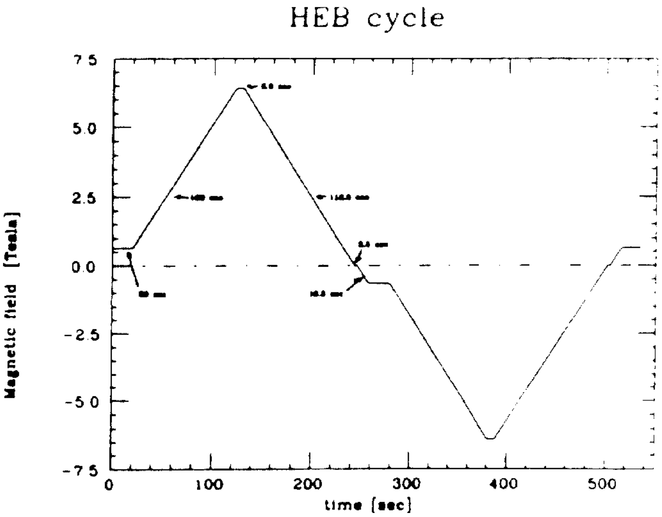

Figure 6 - HEB operating cycle

References

1. M.J. Lamm, *et al.*, "Bipolar and Unipolar Tests of 1.5m Model SSC Collider Dipole Magnets at Fermilab", *Proceedings this conference.*