Extraction System Design for the SSC Low Energy Booster

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Abstract

The Low Energy Booster (LEB) is the first of 3 booster synchrotrons of the SSC accelerator complex. It will accelerate protons from an injection momentum of 1.22 GeV/c to a final momentum of 12 GeV/c, cycling at a frequency of 10 Hz. A single-turn, vertical extraction system has been designed to extract the proton beam from the LEB within the possible machine operation tune range. At extraction, a set of five bump dipoles will be used to vertically displace the central orbit by approximately 1.5 cm at the entrance of the first septum magnet. A fast, ferrite kicker will be used to sweep the proton beam past the septa to initiate the extraction process. The physics parameters and the preliminary designs for the LEB extraction elements are also given.

I. INTRODUCTION

The LEB lattice[1,2,3] has a three-fold symmetry with separate arcs and long straight sections. The overall length is 570 m in order to provide adequate azimuthal space for the required hardware. Each of the three straight sections has a vertical tune of 1.0 effectively increasing the periodicity of the lattice with respect to a polarized beam and therefore reduces the number of depolarizing resonances to be crossed. The horizontal tune across each straight section has been adjusted to achieve the overall non-integer tune in that plane. One of the straight sections (S2) will be used for the extraction process; the other two accommodate the injection and the rf system, respectively. In Figure 1, the lattice functions of the straight section are shown.

The extraction system has been designed to extract a 12 GeV/c proton beam from the LEB in both the collider fill mode and the test beam mode with the normalized transverse beam emittance (rms) being 0.6 π mm-mrad and 4.0 π mm-mrad, respectively. It should provide the same extracted central orbit at the septum magnets for all possible working points; the LEB can be operated with tunes ranging from 10.9 to 11.9 in both horizontal and vertical planes. It is also required that the extraction system fit into the LEB straight section and have no effect on the three fold symmetry of the LEB lattice.

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

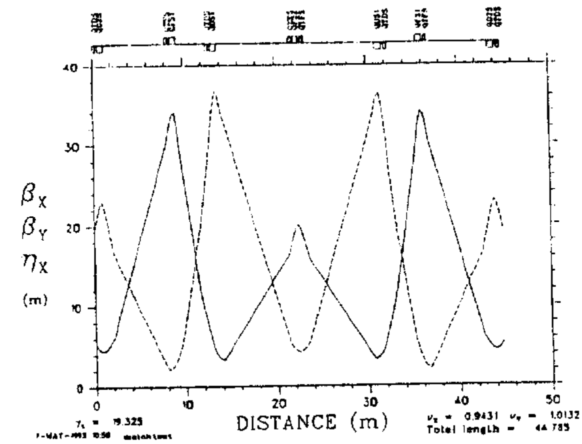

Figure 1. Lattice Functions of the LEB Straight Section

II. THE EXTRACTION SYSTEM DESIGN

A. Beam Optics

Figure 2 shows the layout of the extraction system in the LEB S2 straight section. It also shows the bumped orbits (broken curves) and the extracted orbit (solid curves) in the vertical plane at several different LEB working points. The orbits are calculated by tracking the protons with the code DIMAD.[4] The system consists of a fast kicker, 2 septum magnets and 5 slow bump magnets. The kicker magnet is positioned right after the vertical focusing quadrupole QDS1, and 2 septum magnets one cell downstream. Once the proton beam reaches the final momentum of 12 GeV/c, the slow bump magnets are powered to steer the circulating beam slowly towards the septum several milliseconds before the kick. Then the fast kicker deflects the beam across the septum where it receives additional deflection to leave the machine.

Each of the 5 bump magnets has its own independent power supply so their magnetic field can be independently adjusted in order to generate an adequate vertical displacement at the septum for all possible working points. Once the kicker magnet is turned on, the same extracted orbit will be achieved at the entrance of the first septum regardless of where the LEB is operated, as is evident in Figure 2. Bumps 1 and 2 are positioned before and after the kicker and deflect the orbit by about 15 mm towards the septum depending on the LEB working point. Located right in front of the septum magnet, bump 3 is used to adjust the

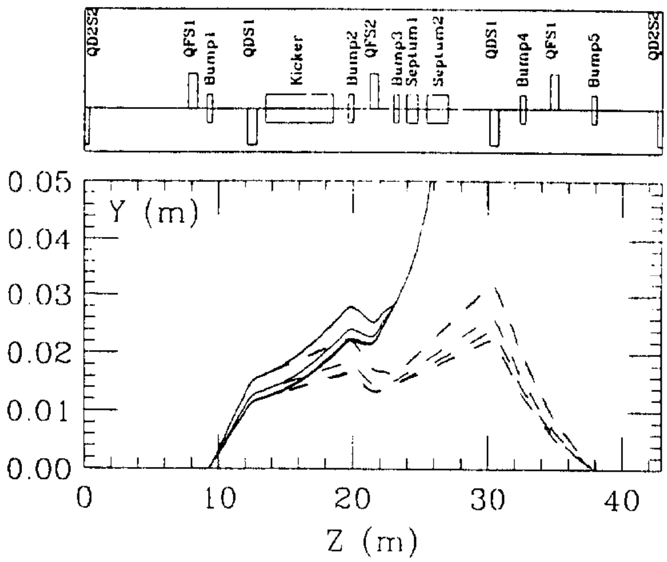

Figure 2. Layout of the Extraction System and the Central Orbit for Bumped and Extracted beam

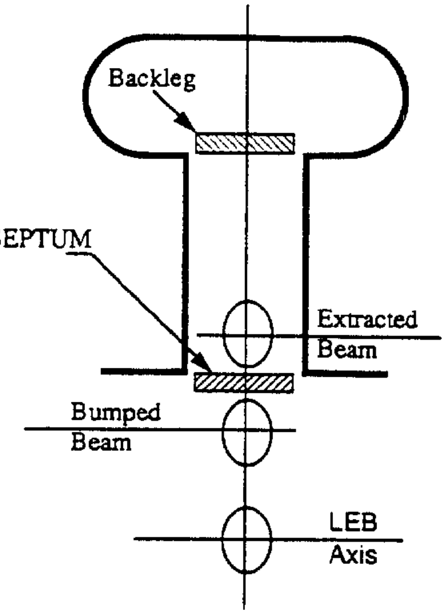

Figure 3. Cross Section at the Entrance of the First Septum Magnet Showing Sizes and Locations of Beams.

angle of the proton beam entering the first septum magnet. Bumps 4 and 5 bring the bumped orbit back to the median plane within the extraction straight section. The maximum deflection angle required for the bump magnets is about 5.0 mrad.

In order to minimize the kicker strength and achieve the bending required to extract the 12 GeV/c proton beam, two septum magnets are used. The first has a 3 mm thick septum and deflects the proton beam by 5 mrad; the second has a 7 mm septum and provides a 50 mrad deflection angle.

The orbit displacement, Δ, generated by a kick δ at the septum is given by:

$$\Delta = \delta\sqrt{\beta_1\beta_2}sin(\phi_2 - \phi_1) \quad (1)$$

where β_1, β_2 are the β functions and ϕ_1, ϕ_2 are the betatron phases at kicker and septum, respectively. For a kicker with a length of L, Δ is given by:

$$\Delta = \frac{\delta}{L}\sqrt{\beta_2}\int_0^L \sqrt{\beta_1(s)}sin(\phi_2 - \phi_1(s))ds \quad (2)$$

The required orbit displacement is determined by the proton beam size at extraction and the thickness of the septum. As indicated above, a 3 mm septum is used in the first septum magnet; the maximum vertical half width of the beam at the first septum is about 4.7 mm (3 σ test beam). More displacement is needed for the closed orbit excursion. About 15 mm orbit displacement at the first septum is required to move the proton beam to the other side of the septum. Figure 3 shows beam sizes and locations at the entrance of the first septum magnet. The kicker strength, δ, is given by:

$$\delta = \frac{\Delta L}{\sqrt{\beta_2}\int_0^L \sqrt{\beta_1(s)}sin(\phi_2 - \phi_1(s))ds} \quad (3)$$

Both the analytic as well as tracking results show a kicker strength δ of 1.5 mrad will be adequate.

B. *The Kicker Magnet*

The extraction kicker has an integrated strength of 600 G-m, and is made up of eight modules to achieve a rise-time of 80 ns. With total magnetic length of about 5.3 m, it has a maximum field of about 115 G. With this rise-time, two to three beam bunches (spaced 16.68 ns apart at 12 GeV/c) are lost due to partial kicker deflection with the head and tail bunches of the extracted beam being sheared somewhat. The aperture of the kicker magnet is 50 mm by 70 mm to accommodate the maximum proton beam size at the injection energy of 600 MeV. The magnetic field variation $\Delta B/B$ is no more than $\pm 1.0\%$ across the good field region of 20 mm by 40 mm. A more detailed paper about the kicker magnet design is included in these proceedings.[5]

C. *The Bump Magnets*

Figure 4 shows the cross section of the bump magnet. The required maximum integrated strength is 0.18 T-m. With a magnetic length of 0.45 m, the maximum magnetic field will be 4.0 kG. It is a laminated, H-shaped, 8 turn/pole dipole magnet with a pole gap of 80 mm. A stainless steel vacuum chamber of 75 mm in diameter is placed into the aperture of the bump magnet. The magnetic field variation $\Delta B/B$ is allowed to change no more than $\pm 0.1\%$ within a good field region of 30 mm by 50 mm. The bump magnet is pulsed by a 2 msec half-sine wave with a peak current of 1600 A.

D. *The Septum Magnets*

Figures 5 and 6 show the cross sections of the short and

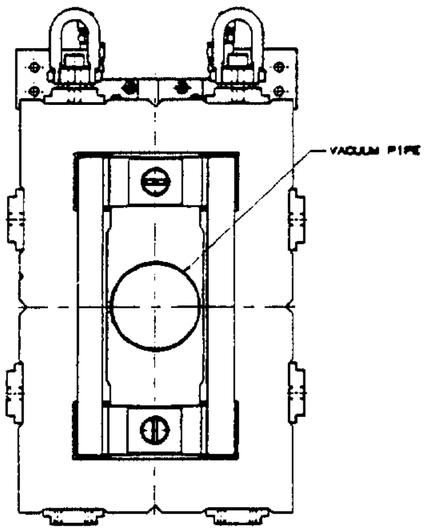

Figure 4. Cross Section of the Bump Magnet

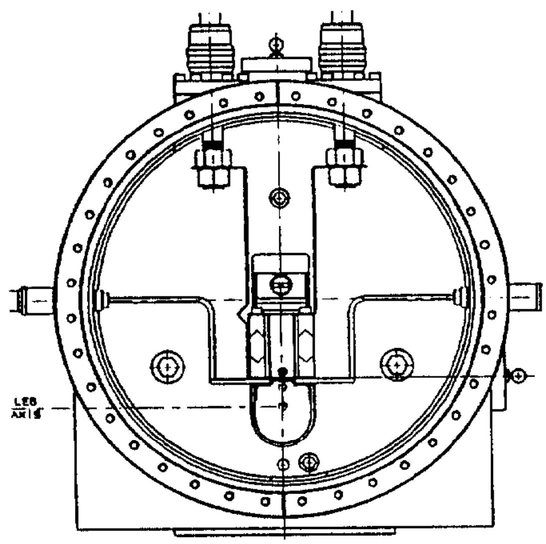

Figure 5. Cross Section of the Short Septum Magnet

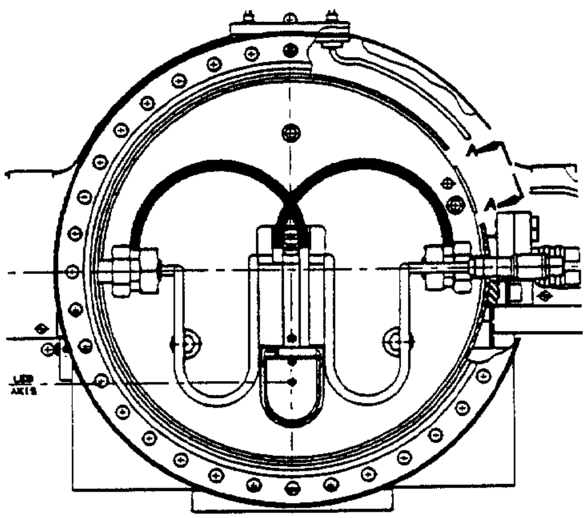

Figure 6. Cross Section of the Long Septum Magnet

Table 1
General Design Parameters of Septum Magnets

Parameter	Short Septum	Long Septum
$\int Bdl$ (T-m)	0.2	2.0
Magnetic Length (m)	0.8	1.6
Maximum Field (T)	0.25	1.25
Field Uniformity	0.24%	0.1%
Peak Current (A)	4780	20400
Power Pulse	1 msec	1.5 msec

long septum magnets.[6] Single turn current sheet septa are used in both magnets with thicknesses of 3 mm and 7 mm, respectively. The design parameters for the septum magnets are given in Table 1. Both magnets are placed into vacuum tanks and vacuum tight feedthroughs provide power and cooling water to the magnets. Special shielding is required to prevent leakage of the magnetic field outside the septa that otherwise would cause emittance growth on the last few hundreds turns prior to powering the kicker. This shielding is accomplished by a U-shaped low carbon steel shell which is brazed to the conductor assembly and is a part of the conductor support structure.

III. REFERENCES

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