THE SUPERCONDUCTING SUPER COLLIDER LOW ENERGY BOOSTER: A STATUS REPORT

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Abstract

In Collider fill mode, the Low Energy Booster (**LEB**) will accelerate 10^{12} protons in 114 bunches from an injection momentum of 1.22 GeV/c to a final momentum of 12 Gev/c, cycling at a frequency of 10 Hz. The most significant extension of present fast-cycling synchrotron technology arises from the requirement that the normalized transverse emittance (rms) of the beam be $\leq 0.6\ \pi\ \mu$m. In an alternative mode, the **LEB** will accelerate five times this current with a normalized transverse emittance $\leq 4\ \pi\ \mu$m. A general overview of the design is presented.

I. Introduction

The Superconducting Super Collider will utilize an acceleration chain consisting of a linac followed by three synchrotrons in order to achieve the final required injection momentum. The Low Energy Booster (**LEB**) is to be the first synchrotron in this series. The general design specifications for the **LEB** are given in Table 1.

Parameter	Value
Injection Momentum (GeV/c)	1.22
Extraction Momentum (GeV/c)	12.0
Repetition Rate (Hz)	10
Circumference (m)	570
Harmonic Number	114
ϵ^*_{rms} (π mm-mrad)	0.6
Particles/bunch	1×10^{10}

Table 1: **LEB** Design Parameters

II. Lattice

The basic lattice design constraints were a small circumference to minimize space charge effects, adequate azimuthal space for the required hardware, and sufficiently large γ_t to avoid crossing transition and to provide an adequate slip factor at extraction to support cogging procedures. Several alternative lattices were explored in light of these specifications and those given in Table 1. A more detailed discussion of the design philosophy and concepts involved in these considerations [1], and tracking evaluations [2] are given in papers in these proceedings. The lattice chosen for the **LEB** has three-fold symmetry. The machine layout is shown in Figure 1 and basic lattice parameters are given in Table 2. Figure 2 shows lattice functions at nominal tune for one sixth of the machine.

Each of the three arc regions consists of four cells, each with a horizontal tune of 0.75, providing an integer horizontal tune of three across each arc. This results in zero dispersion in each of the three straight sections. The arc regions have a slight deviation from the integer condition in the vertical plane to achieve the required overall non-integer tune in that plane.

Parameter	Nominal Value	Range
ν_x	11.65	10.85 - 11.85
ν_y	11.60	10.8 - 11.8
χ_x (natural/corrected)	-15.7/0	-14.0 - -16.5/0
χ_y (natural/corrected)	-17.7/0	-15.0 - -18.5/0
γ_t	22.1	24.4 - 21.9

Table 2: **LEB** Lattice Parameters

Each of the three straight regions has a vertical tune of 1.0, effectively increasing the lattice periodicity with respect to polarized beam, and therefore, reducing the number of depolarizing resonances to be crossed. The horizontal tune across each straight region has been adjusted to achieve the required overall non-integer tune in that plane. One straight region, labled S1 in Figure 1, will be used for injection, specialized diagnostics, and additional rf accelerating cavities should this prove necessary. A second straight region (S2) will be used for extraction, and

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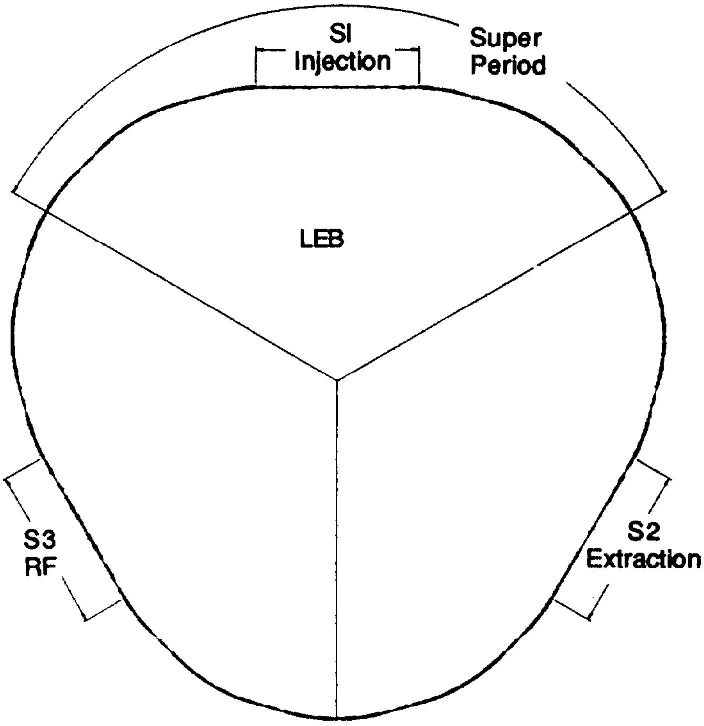

Figure 1: Low Energy Booster Layout

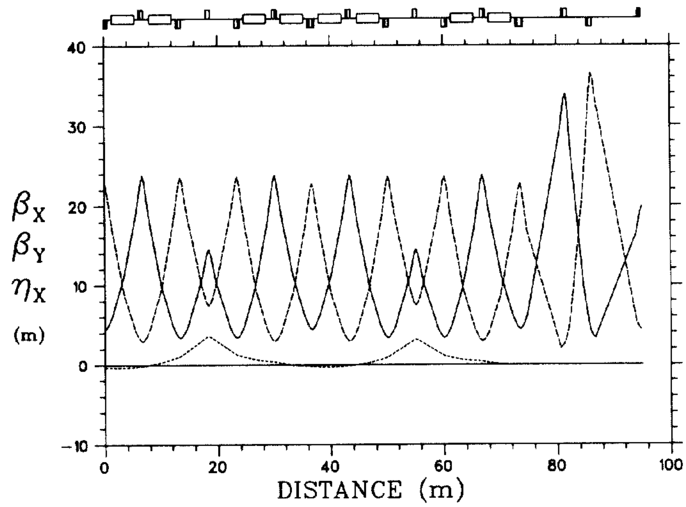

Figure 2: Low Energy Booster Lattice Functions

the third straight region (S3) will be primarily used for rf systems. To maintain the option of accelerating polarized beam, space has been allocated in the straight regions for later addition of a partial Siberian snake and pulsed quadrupoles to jump intrinsic depolarizing resonances.

The required magnetic hardware is specified in Table 3. To achieve adequate tracking over the entire acceleration cycle, the dipoles and quadrupoles will be powered in series by a single resonant circuit system. There will be eight types of quadrupoles differing only in length. Associated with each quadrupole will be a beam position monitor and a central-orbit correction dipole correcting in the plane of focus of the quadrupole. Trim quadrupoles are associated with most of the quadrupoles to correct for tracking errors, the half-integer resonance, and to provide a tune adjustment capacity of one integer in each plane.

Magnet Type	length [m]	Total Number
Dipole	4.0	48
Quadrupole	0.57 - 0.71	90
Sextupole	0.3	48

Table 3: **LEB** Lattice Magnetic Elements

III. Space Charge Considerations

Although the beam intensity requirement for the **LEB** is relatively modest compared to existing machines, the required small beam emittance results in a significant tune depression. In terms of the Laslett tune shift, the tune depression is $\approx$0.5 at an injection momentum of 1.22 GeV/c. Therefore, the effects of space charge are considered a major constraint with respect to the beam dynamics. Certainly a smaller space charge induced tune shift is preferable. However, the maximum allowable tune shift is not a well defined number. Experimental results of existing machines indicate that a tune shift of even more than 0.5 may be acceptable. Machine parameters such as resonance strengths, superperiodicity, or operating transverse and synchrotron tunes all have a bearing on the resultant acceptable tune depression.

To explore the relevant parameter space, a code continues to be developed which employs multi-particle tracking with the transverse dynamics of the thin lens code TEAPOT, the space charge force introduced as kicks, and includes synchrotron oscillations and acceleration. Emittance evolution as well as the particle distribution are simulated as a function of time. A more detailed paper is included in these proceedings [3].

IV. Injection

Microbunches injected from the linac into the **LEB** will be sheared and momentum-compressed to reduce space charge effects and rf voltage requirements. The longitudinal emittance (rms) of the microbunches will be 6.0×10^{-7} eV-sec with an energy spread (rms) of 0.11 MeV and bunch length (rms) of 1.6 cm.

Utilizing four turn injection of stripped H^- similar to that implemented at FNAL, the beam will be injected into the **LEB** with a momentum of 1.22 GeV/c, with each turn placing nine linac microbunches into each **LEB** bucket. The linac frequency will be adjusted such that the 36 linac microbunches will be evenly spaced within an **LEB** bucket. An important criteria for the capture process is the avoidance of significant longitudinal bunching to minimize the space charge induced dilution of the transverse emittance. The rf requirements have been evaluated using ESME and details are presented elsewhere in these proceedings [4]. For ≈15 turns the rf voltage will be maintained at a low value to allow the microbunches to debunch. The rf voltage will then be increased rapidly for ≈1 ms, when a bucket area of 0.04 eV-sec will be achieved, and maintained at this level until ≈3 ms. In order to reduce particle loss, the bucket area will then be increased to 0.054 eV-sec by ≈5 ms. Tracking simulations utilizing ESME predict a capture efficiency of ≈98 %.

V. RF Systems

The requirements for rf voltage are established by the sinusoidal magnet ramp, and by the requirements for bucket area to contain the accelerated beam. The initial part of the bucket area profile was developed to optimize capture as described in section IV. The bucket area is kept constant from 5 ms to 30 ms in the acceleration cycle, after which time it is allowed to grow smoothly to ≈0.32 eV-sec. The bunch area remains constant at ≈0.038 eV-sec.

RF System Parameter	Value
Injection Frequency (MHz)	47.513
Extraction Frequency (MHz)	59.776
Maximum Circumferential Voltage (kV)	765
Maximum Synchronous Phase (°)	65.5
Maximum Energy Gain per Turn (keV)	645
Maximum Slot length available for rf (m)	25

Table 4: RF System Parameters

The limited space available for rf leads to a requirement for maximum sustainable voltage on each gap. Relatively high peak voltages and large bandwidths lead to a preference for low-loss, orthogonally biased ferrite [5]. The reference cavity, chosen after careful consideration of a wide range of potential designs, is based on an existing design [6], presently under test at TRIUMF. These tests have satisfactorily addressed the critical issue of managing eddy current heating in the tuner. As the TRIUMF KAON Booster will cycle at 50 Hz, compared to 10 Hz for the **LEB**, this problem can be regarded as solved. A more serious problem is designing the cavity to minimize rf power dissipated in the ferrite, and maximizing the heat removal capability of the tuner, so that the highest possible gap voltage can be sustained, and the number of cavities minimized. This exercise is subject to the severe constraints of minimum construction cost and maximum utilization of ferrite. The most significant advance has been the adoption of a scheme which provides direct fluid cooling to the ferrite surfaces, and a modest change in tuner configuration which reduces the volume of ferrite required by about a factor of two, relative to the design under test.

VI. Longitudinal Matching

Details of the longitudinal matching for injection into the second synchrotron, the Medium Energy Booster (**MEB**) are given elsewhere [7]. Achieving the necessary longitudinal **LEB** to **MEB** match by adjusting only rf parameters would require an rf voltage at the end of the **LEB** cycle of ≈20 kV. This low a voltage is felt to be problematic. Therefore, it is proposed to jump the phase near the end of the **LEB** ramp cycle to the unstable region, let the bunch shear, and then restore the phase to the stable point. Tracking in the **MEB** of the bunch so created shows this procedure to be adequate and allows the rf voltage at the end of the **LEB** cycle to be ≈80 kV.

VII. Extraction

Single-turn, vertical extraction will be used. A set of three orbit bump dipoles will be used to vertically displace the central orbit by approximately 1.5 cm. A fast, ferrite kicker will be used to vertically sweep the beam past a thin magnetic septum to initiate the extraction process.

VIII. References

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