H^- INJECTION INTO THE LOW-ENERGY BOOSTER OF THE SSC

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ABSTRACT

Protons are accumulated into the low-energy booster of the SSC by utilizing $H^- \rightarrow H^+$ conversion in a 225-μg/cm^2 carbon stripping foil. Synchronous injection is performed for 26 turns into stationary rf buckets, thereby allowing operation with variable bunch spacing. By injecting the beam offset in x and y we obtain the required rms normalized transverse emittance area of 0.75 π mm-mr. Similarly the required rms longitudinal emittance area of $1.75\pi \times 10^{-3}$ eVs is obtained by injecting single linac micropulses, centered at $\phi = 0$, and $dp/p = +0.12\%$, into each 49.9-MHz rf bucket formed with an rf voltage of 350 kV. The transverse space-charge tune shift is -0.17 for 10^{10} protons/bunch accumulated at 600 MeV.

INTRODUCTION

The function of the low-energy booster (LEB) is to accumulate 10^{10} protons per bunch into as many as 72 bunches, and accelerate them up to a final momentum of 8.45 GeV/c for transfer into the medium energy booster (MEB). For each bunch the required beam quality is for a rms normalized transverse emittance ε_t of 0.75 mm-mr and rms longitudinal phase space area A_z of $1.75\pi \times 10^{-3}$ eVs. The input linac beam is assumed to be of order 3.8×10^8 H^- per microbunch with $\varepsilon_t = 0.45$ mm-mr and $A_z = 1.7\pi \times 10^{-5}$ eVs (actually these may be smaller). Therefore some scheme must be incorporated to increase the linac emittances to the required final values during the injection. In this paper we describe how the required beam quality is obtained during the injection process. Multiparticle simulations are carried out to demonstrate the efficiency of the process.

THE MACHINE

Figure 1 shows a plan view of the latest version of the ring.[1] It is in the shape of a racetrack with two 180° arcs with dispersion suppressors, and two long straight sections, each of length 30.83 m. The straight sections are used for beam transfers and rf cavities. Table I lists the basic ring parameters.

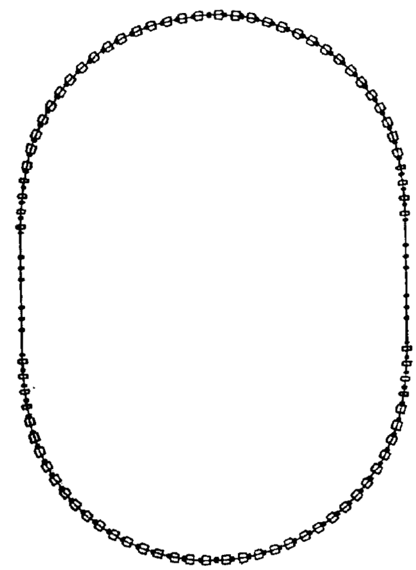

Fig. 1. Plan view of the Low Energy Booster. Circumference is 342.71 m.

Table 1. Parameters of the Low-Energy Booster.

Circumference (m)	342.711
Momentum Range (GeV/c)	1.22–8.45
Repetition Rate (Hz)	10.0
Number of Protons/Pulse	7.2×10^{11}
Betatron Tunes Q_x, Q_y	11.84, 11.78
Chromaticity Q'_x, Q'_y	−15.3, −15.6
Transition Gamma	10.32
RF Harmonic	72

THE INJECTION STRAIGHT SECTION

The injection will take place in the 6-m drift in the center of the long straight section. Figure 2 shows an elevation view of the H^- injection and circulating proton beam envelopes in that section. During the injection period the circulating proton beam is displaced vertically by the orbit bumps 0_1 and 0_2 and traverses the stripping foil at a vertical position 3 1/3 cm above beam centerline. The incoming H^- are sent downward through a current septum S and into 0_1. The initial point is at $y = 347$ mm and $y' = -166.67$ mr. The magnetic fields in S, 0_1, and 0_2 are held at 0.45 T. The magnetic lengths are 1.5 m, 1.0 m, and 1.0 m, respectively.

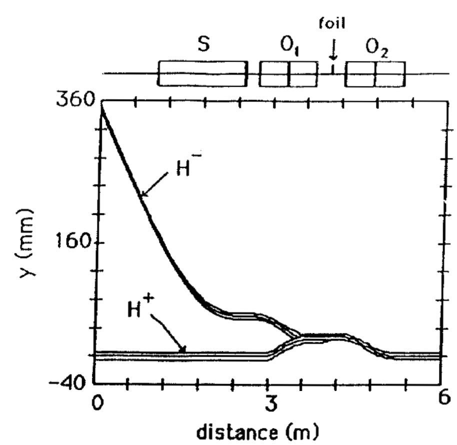

Fig. 2. Elevation view of beam envelopes in the 6.0-m injection straight section.

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The H^- strip to H^+ in the foil at about 3.5 cm above beam centerline. Greater than 95% stripping efficiency is obtained with a carbon foil with thickness $\rho\ell = 225\ \mu g/cm^2$. After the injection, the bumps are rapidly reduced to zero so the protons cease to traverse the foil during the remainder of the cycle. The lower edge of the foil can be at, e.g., $y = 2.5$ cm.

INJECTION INTO STATIONARY BUCKETS

The SSC users reserve the option for variable bunch spacing. These spacings would be the nominal 4.75 m, as well as 9.5 m and 19.0 m. In the LEB these three cases correspond to all buckets filled, every other bucket filled, or every fourth bucket filled. Furthermore the "empty buckets" should really be free of beam. These requirements preclude use of the standard fill and adiabatic capture technique. Clearly the most efficient filling mechanism is injection of a single microbunch into an existing 49.9-MHz bucket.

It was decided to use 350 kV/turn rf voltage during the injection. A multiparticle simulation was used to study the injection process. Figure 3(a) shows the position and extent of the injected micropulses into the existing buckets. The center of the beam is placed at $[\phi_c, (dp/p)_c] =$

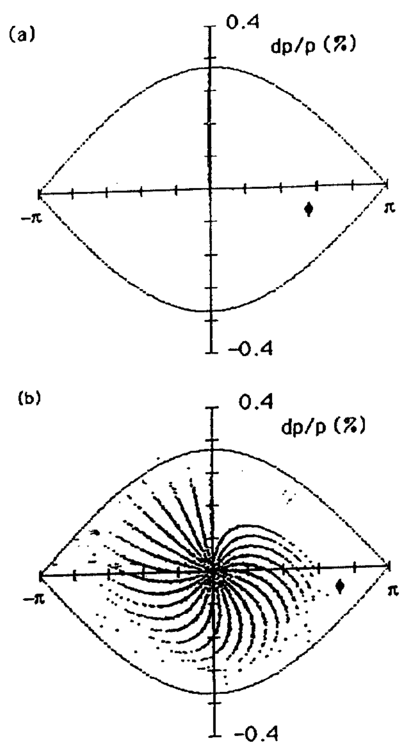

Fig. 3. (a) Injected microbunch within an existing 49.9-MHz rf bucket. (b) Longitudinal phase space after 26 turns of injection. Rms single bunch area $A_z = 1.82\pi \times 10^{-3}$ eVs.

$(0, +0.12\%)$, i.e., the beam is injected higher in momentum by 1.2 MeV/c. The rms area of the microbunch was taken to be the linac value $A_z = 1.7\pi \times 10^{-5}$ eVs. The width and height of the microbunch were optimized to $\sigma_\phi = 0.0107$ (relative to the 49.9-MHz rf) and $\sigma_p/p = 0.05\%$. To fill longitudinal phase space we inject for 26 turns (roughly one synchrotron oscillation). Figure 3(b) shows the longitudinal phase space as predicted by the simulation program. The rms bunch area is $1.82\pi \times 10^{-3}$ eVs, just slightly larger than the desired value $A_z = 1.75\pi \times 10^{-3}$ eVs. The ϕ and dp/p projections of Fig. 3(b) are shown in Figs. 4(a) and 4(b),

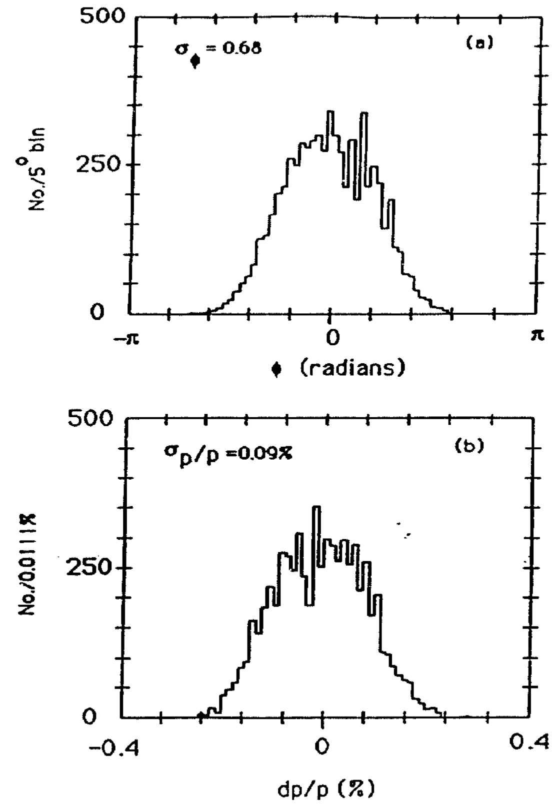

Fig. 4. Projections of Fig. 3(b): (a) $dN/d\phi$; (b) $dN/dp/p$.

respectively. The bunching factor is of order 33% and the rms relative momentum spread σ_p/p is 0.09%.

THE TRANSVERSE PLANES

The simulation program was used to obtain the proper injection conditions. For the 26-turn simulation it was assumed the linac beam was matched to that of the machine at the foil location. The microbunches were taken to be bi-gaussian in x-x' and y-y' phase spaces with rms normalized emittances $\varepsilon_t = 0.45$ mm-mr. In x-y space the microbunches were injected at average x, y values of 1.3 mm and 35.0 mm, respectively; the bottom foil edge was at $y = +25$ mm. The vertical bump was fixed at 33.3 mm. The injected central divergences x', y' were both assumed to be zero. The output phase space distributions are presented in Figs. 5(a) and 5(b). The normalized rms emittances were found to be in the range of 0.76–0.78 mm-mr which meets the required specification of 0.75 mm-mr. The x and y projections of Figs. 5(a) and 5(b) are both approximately Gaussian with rms value 1.6 mm and 2.2 mm, respectively.

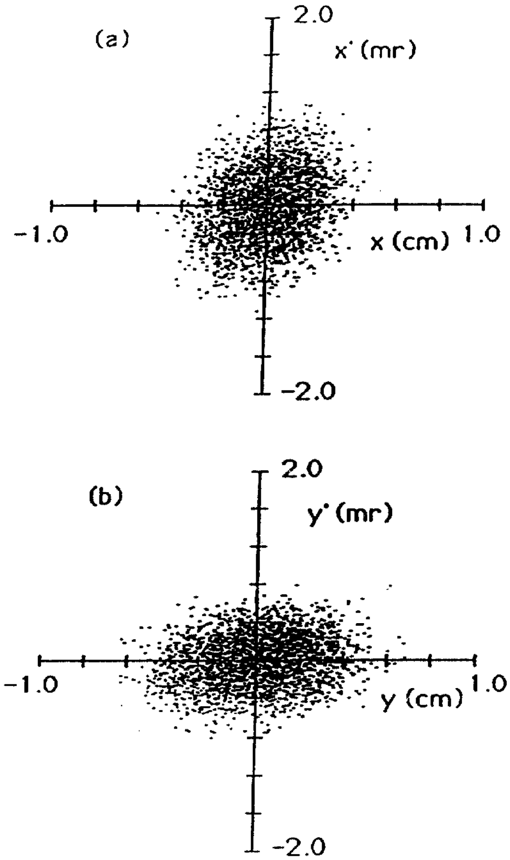

Fig. 5. Injection phase-spaces at the foil location after 26 turns of injection: (a) x-x' distribution; (b) y-y' distribution—y is measured relative to a 3.33-cm bump.

SPACE-CHARGE TUNE SHIFT

The worst case tune shift for Gaussian distributions is given by

$$\Delta Q_y = -\frac{r_p N_b N_p}{4\pi\beta\gamma^2 B\varepsilon_t}$$

where r_p = classical proton radius (1.54×10^{-18} m), N_b = number of bunches (72), N_p = number of protons/bunch (10^{10}), B = bunching factor (0.33), and ε_t = rms normalized transverse emittance (0.75 mm-mr). We obtain $\Delta Q_y = -0.17$ which is certainly within specifications.

COMMENTS

The injection scheme put forth here should easily meet the requirements for 600 MeV H$^-$ injection. If necessary, the present design could work up to 800 MeV H$^-$ injection. If the linac energy is upgraded even further (in order to reduce the transverse emittances), then the injection scheme has to be modified.

REFERENCE

1. L. K. Chen and M. A. Furman, "A Possible New Design of the SSC Boosters," SSC-164.