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RF DEFLECTOR-CHOPPER FOR SSC INJECTOR*

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Abstract In a proposed SSC linac injector, the Low-Energy Booster lattice painting scheme requires a 50-MHz microbunch structure with transverse and longitudinal normalized rms emittances of less than 0.45 π-mm-mrad and 1.7×10^{-5} π·eV·s, respectively, at 600 MeV. A 50-MHz RFQ design does not meet the longitudinal emittance requirements; a 150-MHz RFQ can do so, but requires a chopping scheme that produces a clean 50-MHz beam structure without degrading emittance. We present an RF deflector-chopper conceptual design that converts a 150-MHz RFQ beam into a 50-MHz microbunch beam structure while matching transversely and longitudinally to a following 450-MHz DTL. Multiparticle simulation with 3-D space charge shows negligible emittance growth. Output beam emittances are factors of 3 below requirements; further acceleration to 600 MeV should produce only small additional growth. The chopper is 54 cm long, comprising an RF deflector, two rebunchers, five small permanent magnet quadrupoles, and a beam dump. Similar schemes could use a 200- or 250-MHz RFQ for even smaller longitudinal emittance.

INTRODUCTION

A proposed lattice painting scheme[1,2] for the Superconducting Super Collider (SSC) Low-Energy Booster (LEB) uses a 3-mA H^- beam (3.8×10^8 H^- per bunch) with a 50-MHz microbunch structure. Transverse and longitudinal emittance requirements are, respectively, 0.45 π-mm-mrad and 1.7×10^{-5} π·eV·s (rms normalized). A 50-MHz, 2.5-MeV radio-frequency quadrupole (RFQ) beam dynamics design has been completed[3], but simulations of this RFQ predict transverse and longitudinal emittances of 0.18 π-mm-mrad and 2.6×10^{-5} π·eV·s, respectively; longitudinal emittance is too large. However, a 150-MHz RFQ design easily satisfies emittance requirements with transverse and longitudinal emittances of 0.14 π-mm-mrad and 0.44×10^{-5} π·eV·s. Higher-frequency RFQs can have even smaller emittances.

We present a conceptual design of an RF deflector-chopper in which a high-frequency beam is converted to a lower-frequency beam structure with

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little emittance growth. This system selects every third bunch from the 150-MHz, 9-mA, 2.5-MeV RFQ output beam for transmission, converting the beam to a 50-MHz, 3-mA structure. The system also matches the beam from the RFQ into the following 450-MHz DTL.

CHOPPER DESIGN

Funneling, using an RF deflector, has been proposed as a method of increasing brightness in high-current beams by interlacing the bunches of two converging bunched beams to form a single beam of twice the frequency and current.[4] Such a funnel is the subject of an experimental program at Los Alamos.[5] The RF deflector-chopper is a modification of the funnel concept. The direction of travel is opposite to that of a funnel, and the beam is split into separate beams of lower frequency. In this design, the frequency is reduced by a factor of 3 as shown in Figure 1.

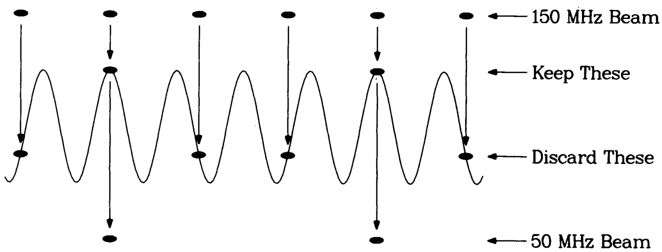

FIGURE 1 Beam structure modification by a 200-MHz deflector.

For beams with appreciable space charge in which emittance growth is of concern, transport-line design should minimize charge-redistribution emittance growth[6] by keeping constant (or changing only slowly) both transverse and longitudinal focusing strength and by proper matching between different accelerator structures. These considerations were kept in mind in the present design (Figure 2). However, because space-charge effects are not of major importance here, the line can be shorter and the changes more abrupt than if a high-current beam were being transported.

The transport line at 2.5 MeV consists of three FODO focusing periods of different lengths. Permanent-magnet quadrupoles provide increasing transverse focusing strength, matching transverse beam parameters to the following DTL. The first and third periods contain 150-MHz rebunchers that match the longitudinal beam parameters into the DTL. The second focusing period contains the RF deflector. Table I lists the beam elements and their dimensions and field gradients or voltages. Beam apertures are not critical but have been set at 1.6-cm diameters in the quadrupoles Q1, Q2, and Q4, 3 cm in Q3, and 1.2 cm in the deflector.

The bend-plane (x-z plane) cross section of the RF deflector is shown in Figure 2. The two oval electrodes extend in the y-direction (perpendicular to

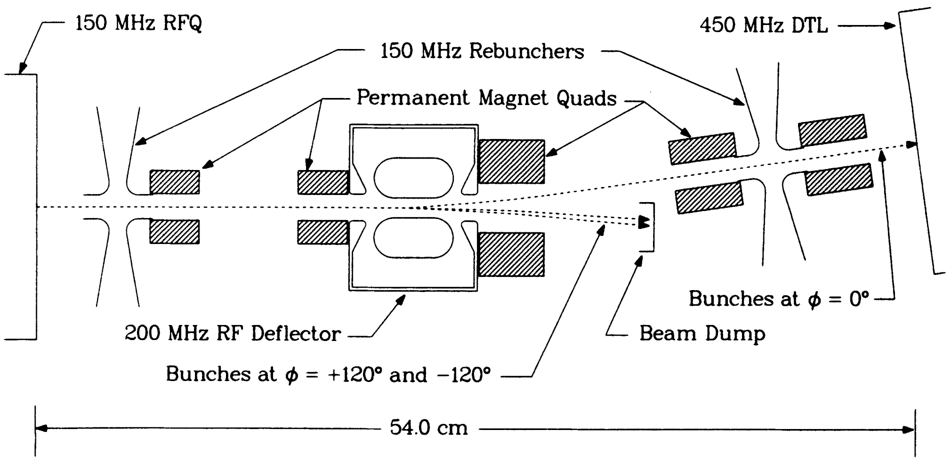

FIGURE 2. The RF deflector-chopper for the SSC injector.

Table I Beamline elements.

Element	Type	Length	Field
D1	Drift	3 cm	--
R1	150-MHz rebuncher	4 cm	241 KV
Q1	Defocusing (in x) quad	3 cm	76.58 T/M
D2	Drift	6 cm	--
Q2	Focusing quad	3 cm	92.19 T/M
Def	200-MHz RF deflector	8 cm	12.5 MV/M
Q3	Defocusing and deflecting quad	4 cm	70.00 T/M
D3	Drift	8 cm	--
Q4	Focusing quad	4 cm	99.37 T/M
R2	150-MHz rebuncher	4 cm	314 KV
Q5	Defocusing quad	4 cm	131.81 T/M
D4	Drift	3 cm	--

the plane of the bend) near the beamline whereas the noses on the end walls are cylindrically symmetric around the beamline. In a similar device being constructed at Los Alamos, electrodes are mounted on half-wavelength rods, and one nose contains a permanent-magnet quadrupole. The electrodes are slightly less than $\beta\lambda/2$ in length along the beamline. If the deflector could produce a uniform transverse field of length $\beta\lambda/2$ with a $\sin(\omega t)$ time dependence, and if the synchronous particle with energy K were at the center of the deflector at the time of maximum field strength E, then the deflection of the synchronous particle from the electric field alone would be

$\theta = (\beta\lambda/2\pi)(eE/K)$. It can be shown that the force from the RF magnetic field goes roughly as β^2; this was neglected in our calculations.

A real deflector cannot produce a uniform transverse field, of course; the electric field components from the deflector are shown in Figure 3. The

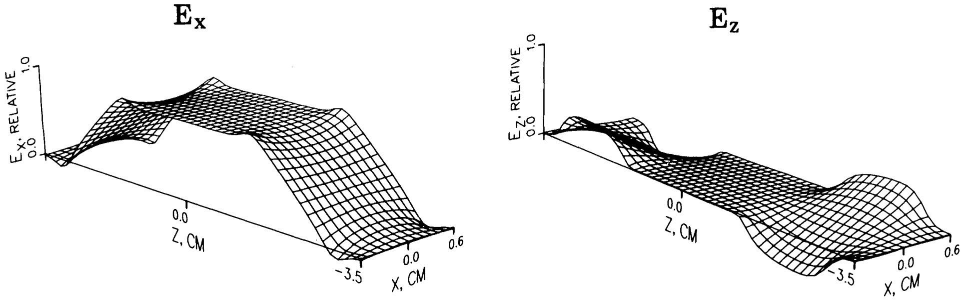

FIGURE 3 The RF deflector electric fields.

nonuniformity of the transverse (E_x) field, the presence of the longitudinal (E_z) field coupled with the changing transverse coordinates of the particles, and the phase spread of the bunch coupled with the time dependence of the field, all contribute to emittance growth in the RF deflector. This emittance growth can be reduced by shaping the deflector plates and noses for the best field uniformity, making the bunch envelope small in the plane of the bend to avoid regions of field nonuniformity, shortening the bunch to lessen the effect of the time-dependent field, and keeping the angle of deflection small. In the present design, all these techniques were used to some extent. There are other emittance-growth-reducing techniques such as introducing a third harmonic to flatten the field time-dependent wave-shape, using a second deflector to bend the beam in the opposite direction thereby cancelling some of the aberrations, and using a lower-frequency deflector; these were not necessary in this design. The first quadrupole downstream from the deflector is defocusing in x and gives further deflection to the beam because the beam enters it off-axis. In this design, the RF deflector bends the beam through 4.4° and the defocusing quadrupole provides 3.6° for a total bend of 8°.

A modified version of the Los Alamos PARMILA particle-following code was used for these beam dynamics calculations. Approximately 4000 macroparticles generated by the PARMTEQ calculation of the 150-MHz RFQ were followed through the chopper line. Space-charge effects were calculated using 3-D charge-cloud interactions. Particles were integrated through the deflector in small steps using the electric field maps shown in Figure 3.

RESULTS AND DISCUSSION

Beam rms-radius envelopes are shown along the beamline in Figure 4. The 90% beam radius is everywhere below 3 mm. In one simulation, the apertures were set at a 5-mm radius throughout the line and the resulting transmission was 99.97%.

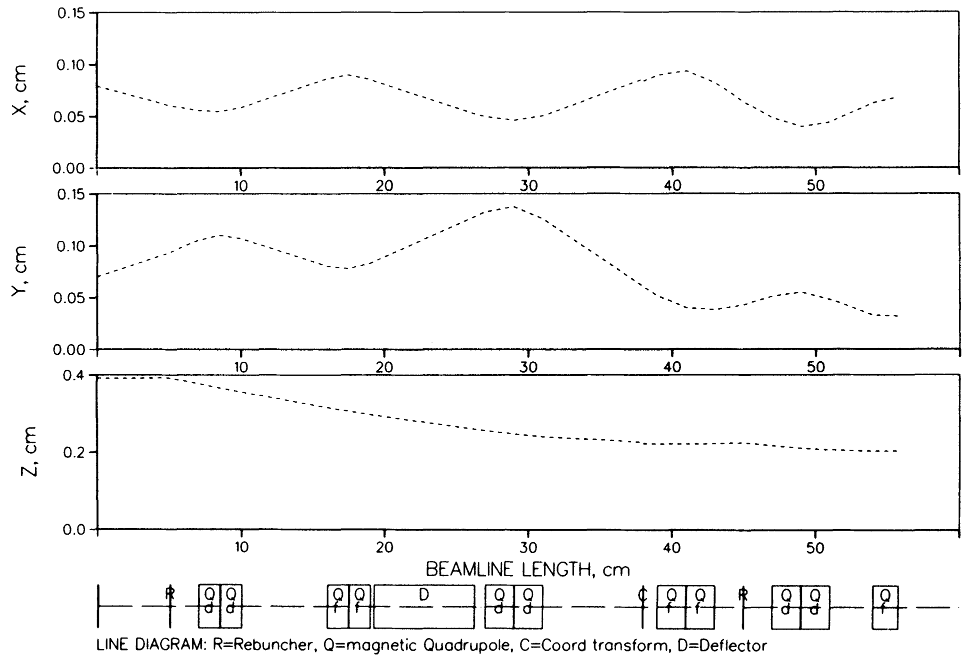

FIGURE 4 RMS beam envelopes.

Table II Emittances, rms normalized

	ε_x (π-mm·mrad)	ε_y (π-mm·mrad)	ε_z (π·eV·s)
RFQ output	0.14	0.15	0.44×10^{-5}
Chopper output	0.16	0.15	0.44×10^{-5}

A transverse particle plot (Figure 5) at the position of the beam dump, 1 cm upstream from the fourth quad, shows a pattern at about $x = +1.7$ cm (the initial axis is at $x = 0$). This is the bunch that enters the deflector at the proper phase (0°) for maximum positive x-deflection. The other two bunches, at phases of $+120°$ and $-120°$, are deflected in the negative x-direction and are smeared in the x-direction because of the time-dependence of the deflector field. If the beam dump can accept a smaller separation of the desired and undesired beams than that shown in Figure 5, the beam deflection angle and thus the emittance growth of the desired beam can be reduced.

This RF deflector-chopper design, combined with the 150-MHz RFQ and the 450-MHz DTL designs, can produce a beam that satisfies

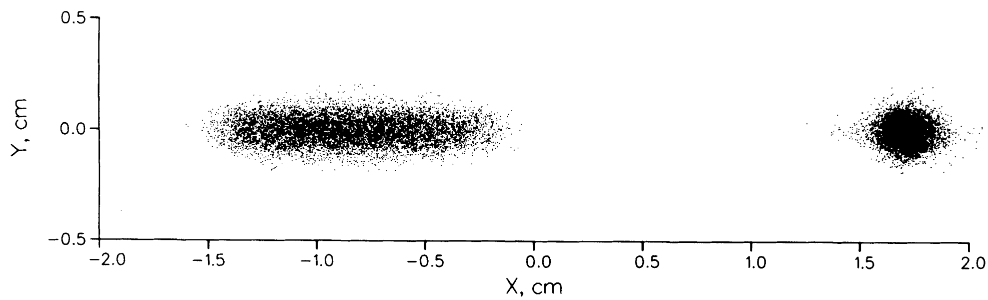

FIGURE 5 Particle plots at beam dump.

requirements for the lattice-painting scheme proposed in Ref. 1. Similar designs could provide beam-structure modifications for other frequency ratios. If desired, bending magnets could be incorporated in drifts D2 and D4 to align the input and output beams to the same beamline.

Chopper designs such as the present example will allow low-emittance beams of high-frequency RFQs to be used when lower-frequency beam structures are desired. Ongoing funneling tests will provide experience for optimum design of such choppers.

ACKNOWLEDGMENTS

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