SSCL-313

Superconducting Super Collider Laboratory

Beam Transfer Between the Coupled Cavity Linac and the Low Energy Booster Synchrotron for the SSC

R. K. Bhandari and S. Penner

September 1990

SSCL-313

BEAM TRANSFER BETWEEN THE COUPLED CAVITY LINAC AND THE LOW ENERGY BOOSTER SYNCHROTRON FOR THE SSC*

R. K. Bhandari and S. Penner

Superconducting Super Collider Laboratory†
2550 Beckleymeade Ave.
Dallas, TX 75237

September 1990

*Presented at the 1990 Linear Accelerator Conference, Albuquerque, NM, September 10–14, 1990.

†Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC02-89ER40486.

BEAM TRANSFER BETWEEN THE COUPLED CAVITY LINAC AND THE LOW ENERGY BOOSTER SYNCHROTRON FOR THE SSC

R. K. Bhandari and S. Penner
Superconducting Super Collider Laboratory*, Dallas, Texas 75237, USA

Abstract

Ion optical design of the transfer line, which will be used to inject H^- beam at 600 MeV from the Coupled Cavity Linac (CCL) into the Low Energy Booster (LEB) synchrotron, is described. Space charge effects of up to 50 mA average beam current have been taken into account.

Introduction

The transfer line must deliver a properly matched, stable and clean beam of small momentum spread and emittance to the stripper foil in the LEB. Nominal emittance at the linac exit is approximately 0.2 π mm-mrad (rms, normalized) in both transverse planes. Simulation studies[1,2] show that the phase space ellipses are almost upright here with β_x=3.13 m and β_y=9.97 m. The longitudinal emittance (rms) is about 268 π keV-deg and β_l=0.0066 deg/keV yielding an rms bunch size of 1.327 deg for the CCL frequency of 1284 MHz. The design average current for collider filling is 25 mA although the rated value for the CCL is 50 mA. The pulse rate is 428 MHz which is the Drift Tube Linac (DTL) frequency. The beam macropulse length is 6.6 μs for collider ring filling and up to 35 μs for the test beam operations.

The transfer line, figure 1, has been designed to perform various functions e.g. beam transport, achromatic bending, phase space matching, etc., with an emphasis on efficient measurement of the beam properties, stabilization and clean-up as well as dumping the beam during tuning. The calculations presented here correspond to matching an LEB beta function of 10 meters and normalized transverse emittance of 0.3 π mm-mrad (rms). An energy compressor RF tank will be used in the line to adjust the longitudinal phase space so that the beam is efficiently captured by the LEB RF system.

Description of the Transfer Line

The line was initially designed and optimized using the TRANSPORT code[3] ignoring space charge effects. Various segments of the line and their design considerations are briefly described in the following sections:

FODO Array

This segment is made up of 21 D and 20 F quadrupole magnets with interquad drift space of 2.38 meters. There are 20 identical unit cells in the array. The phase advance per cell is 90 degrees. These quadrupoles have an effective length of 70 mm and an aperture radius of 15 mm.

Emittance Scraper Segment

The function of the scraper is to remove extreme tails from the beam profile - at most, a few percent of the beam current. Two apertures, separated by approximately 90 degrees of betatron phase, provide the desired emittance limit. First aperture will be placed at the exit of the last quadrupole of the FODO array. A quadrupole doublet Q1,Q2 provides the desired betatron phase advance. The second aperture is placed within a 28 meters drift following this doublet. At the end of this drift space, the doublet Q3,Q4 refocusses the beam into the following spectrometer. Quadrupoles Q1 and beyond have an effective length of 300 mm and an aperture of radius 37.5 mm.

Achromatic Spectrometer

This system is mirror symmetric about its center point where the energy stabilizing and scraper slits will be located. Optical aberrations in the spectrometer are minimized when there is a double waist at the symmetry plane. Energy resolution is maximized by minimizing the horizontal waist size. We achieve the desired waist conditions by adjusting the gradients of Q1 to Q4. Dispersion of the system at the symmetry plane is 1.534 meters and the momentum resolution is 0.04% (rms). Since there is only one constraint on the settings of Q5 and Q6, we chose to excite them to the same pole tip field but with opposite polarity. The dispersion (η) beyond the spectrometer can be adjusted by changing the ratio of fields in Q5 and Q6, while maintaining the condition R_{26}=0 at the symmetry plane. Angular dispersion can be changed by breaking the symmetry, i.e., by setting Q5' and/or Q6' differently from Q5 and/or Q6. Two sextupole magnets in the system are used to correct for the second order field inhomogeneity in the dipole magnets. They are symmetrically placed 35 cm upstream of D1 and 35 cm downstream D1'. The dipoles are rectangular, uniform field magnets, with an effective length of 2 meters.

Emittance Measurement Range

Following the spectrometer, the quadrupole doublet Q7,Q8 is used to produce a double waist near the mid point of a 20 meter long emittance measurement range. Three beam profile monitors will be used for this measurement, the central one being at the double waist location.

Matching Segment

This segment matches the beam on to the stripper in the LEB ring through the injection segment. Quadrupole doublets Q9, Q10 and Q11, Q12, separated by an 11 meters drift space, provide flexible capability to match to a variety of input and output conditions even for beams with high space charge effects. A 12 degrees dipole magnet midway between the two doublets is pulsed on to guide the beam to the second

*Operated by the Universities Research Association, Inc. for the U.S. Department of Energy under Contract No. DE-AC02-89ER40486

beam dump, so that no beam enters the LEB ring during tune-up of the linac or between the LEB fills.

Injection Segment

About 2.8 meter downstream of Q12, the beam enters the injection septum magnet of length 1.407 meters and bending angle 5.66 degrees. The injection bump magnet, 10 cm downstream of the septum magnet, is 0.6 meter long and bends the beam by 2.46 degrees. The stripper is located 10 cm downstream of the exit of the bump magnet.

Second Order Effects

TRANSPORT calculations for the entire transfer line have been carried out to second order. Second order aberrations are found to be negligible, except for the effect of the sextupole component of the dipole fields.

Space Charge Calculations

Space charge effects have been estimated in a linear approximation and the beam line parameters reoptimized using TRACE 3-D interactive code[4]. In the zero beam current case, agreement with TRANSPORT is excellent. Beam envelopes for 5 times the rms emittance (90% beam), obtained using this code, are compared in figure 2, with and without space charge effects of 25 mA average beam current. In both cases, the phase space matching constraints at the stripper are same.

Due to rather long flight paths in the transfer line, space charge effects depend strongly on the energy spread in the beam. They are more pronounced in the case of short bunches like those emerging from the CCL. In view of this, location of the energy compressor cavity in the beam line is very important.

Location of the Energy Compressor RF Cavity

The energy compressor is a coupled cavity tank operating at 1284 MHz and consisting of 20 identical cavities each $\beta\lambda/2$ in length. Its total length is thus 1.85 meters for 600 MeV H^- beam. Synchronous phase, ϕ_s, of the reference particle is - 90 degrees. The rate of change of energy of the ions with charge q arriving at the cavity at phase ϕ is given by:

$$\frac{dw}{dz} = qE_0T\cos\phi$$

where, E_0T is the effective peak accelerating field in the cavity. Requirements on the tank are such that:

1) The rms energy spread (ΔE_{rms}) at the stripper in the LEB is compressed to about 100 keV for longitudinal matching.

2) The half bunch length for the rms beam ($\Delta\theta_{rms}$) at the tank entrance should be about 25 degrees so that most particles see the linear part of the RF waveform.

3) The value of E_0T is as low as possible.

This optimization has been carried out using the TRACE3-D code. First, the tank is placed in one of the drift spaces of the FODO array such that condition (2) is closely satisfied with space charge effects for the desired beam current turned on. Subsequently, E_0T is optimized to obtain the desired energy spread the stripper location.

Various cases corresponding to the average beam currents of 25 mA and 50 mA have been studied. Some of them are summarized in the table 1. While for the 25 mA case it is relatively easy to satisfy the abovementioned conditions, the 50 mA case offers some difficulty. In this case, in order to satisfy condition (2), the tank must be placed at 41.95 meters downstream of the linac exit. It was seen that in the subsequent flight path up to the stripper, space charge effects overcome the energy compression introduced by the tank and the desired energy spread could not be achieved. In view of this, the tank must be moved further downstream in order to satisfy the energy spread constraint at the stripper. This, however, is at the cost of longer bunch length than the desired 25 degrees at its entrance. Figures 3 and 4 show, respectively, variation of the rms energy spread and the half bunch length at the stripper as functions of E_0T for the tank at two different locations. These figures clearly indicate that minimum values of these parameters correspond to a unique value of E_0T which depends on the tank location and the beam current as discussed.

TABLE 1

			At the tank		At the stripper	
$I_{av.}$ (mA)	d (m)	E_0T (MV/m)	ΔE_{rms} (keV)	$\Delta\theta_{rms}$ (deg)	ΔE_{rms} (keV)	$\Delta\theta_{rms}$ (deg)
25	56.65	0.825	673.5	24.95	100.0	31.69
25	46.85	1.130	662.2	20.04	99.8	22.87
50	56.65	0.852	927.1	34.42	99.9	39.40
50	46.85	1.227	913.9	27.65	102.4	22.41
50	41.95	1.302	905.0	24.31	157.6	28.88

d : distance between the linac exit and the tank entrance

In the transverse directions, however, even with space charge effects of up to 50 mA, the beam remains well within acceptable magnet apertures. Desired phase space matching at the stripper is easily achievable by slight tuning of the matching quadrupoles. TRACE-3D readily finds new solutions for the matching quadrupole settings.

Conclusions

The CCL - LEB transfer line has a flexible optical design capable of handling almost twice the nominal linac emittance. Space charge effects of up to 50 mA average beam current have been determined to be tolerable. Longitudinal space charge effects strongly influence the position and excitation of the energy compressor RF tank. Phase space matching to the LEB requirements at the stripper are easy to achieve. Ray-tracing calculations[5] show that fabricational tolerances on all the magnets of the line can be easily met.

Acknowledgements

We greatly appreciate the deep interest and many useful suggestions from Jerry Watson in this work. Many thanks to Deepak Raparia for his help in running the TRACE-3D code.

References

1. SSC Site-specific Conceptual Design Report, December 20, 1989, Chapter 4, p.138.
2. T. S. Bhatia, Los Alamos National Laboratory, private communication.
3. K. L. Brown, F. Rothacker, D. C. Carey and Ch. Iselin, Report No. CERN 80-04, CERN, 1980 and D. C. Carey, Report No. 1546, Fermilab, September 1988.
4. K. R. Crandall, Report No. LA-11054-MS, Los Alamos National Laboratory, August, 1987.
5. R. K. Bhandari and S. Penner, an SSC report (to be published).

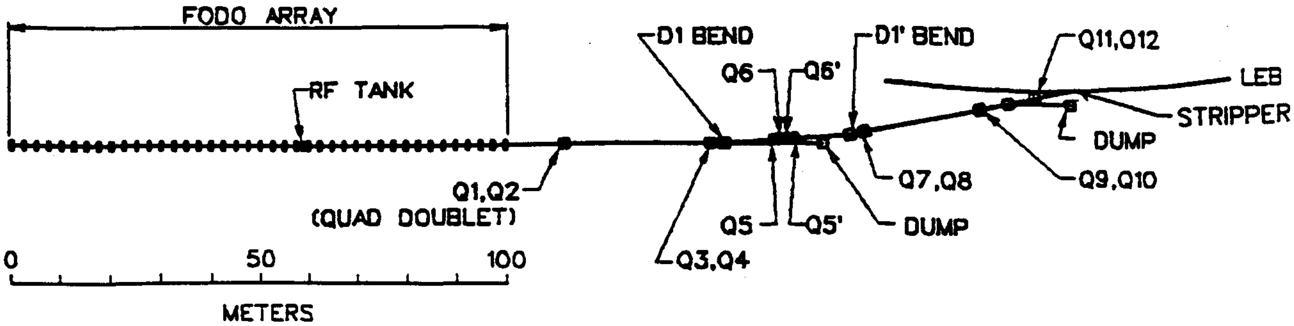

Figure 1: Layout of the beam transfer line between the coupled cavity linac and the low energy booster synchrotron. Q: Quadrupole magnets, and D: Dipole magnets. Total length of the line is about 207 meters.

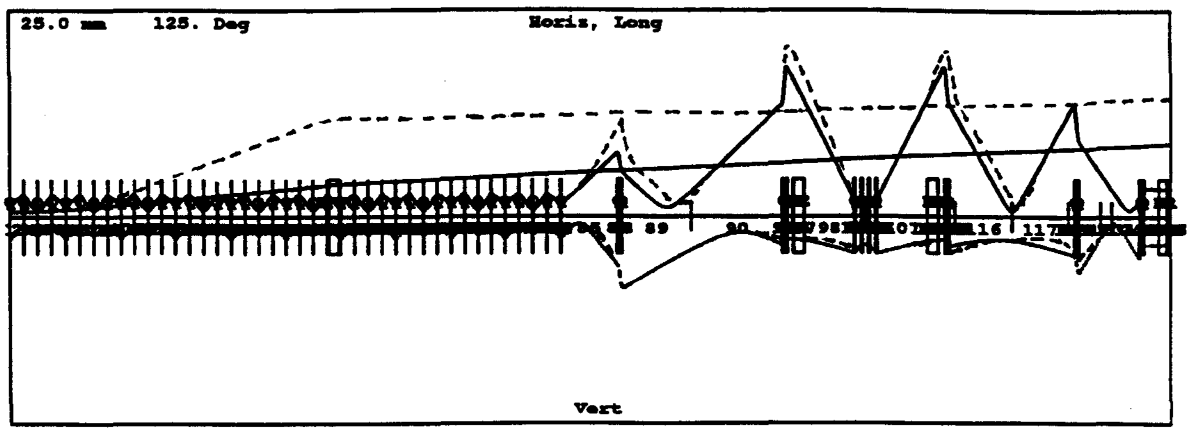

Figure 2: Beam envelopes for 5 times the rms emittance in the transfer line from linac exit up to the stripper in the LEB ring; Full line: Zero beam current; Dotted line: 25 mA beam current. E_0T for the RF tank was set at 0.366 MV/m for the zero beam current and 0.825 MV/m for the 25 mA beam current case.

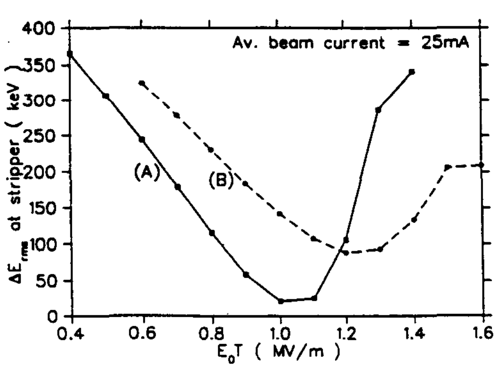

Figure 3: Effect of variation of E_0T on the rms energy spread at the stripper. RF tank is located at, (A) : 56.65 m and (B) : 46.85 m from the linac exit.

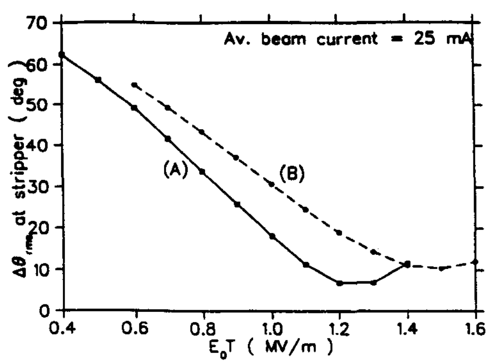

Figure 4: Variation of the rms half bunch length at stripper with E_0T for the cases of fig. 3. Value of $\Delta\theta_{rms}$ at tank entrance for case (A): 24.95° and (B): 20.04°.