200 GeV Beam Transfer Lines at the SSC

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Abstract

Two beam lines have been designed to transfer 200 GeV protons from the Medium Energy Booster (MEB) to the High Energy Booster (HEB) of the SSC injector complex. At 850 m and 2200 m in length, these are the longest beam transfer lines at the SSC and are intended to inject beam into the bipolar HEB in the clockwise and counter-clockwise directions, respectively. The beam optics is designed so as to facilitate easy tuning and commissioning of these lines. Sources of emittance dilution are identified and estimates of their contribution calculated which serve as basis for specifications of dipole field homogeneity and power supply stability.

I. INTRODUCTION

The SSC injector complex consists of a 600 MeV linac, the Low Energy Booster (LEB) - 600 MeV to 12 GeV, the Medium Energy Booster (MEB) - 12 GeV to 200 GeV, and the bipolar High Energy Booster (HEB) - 200 GeV to 2 TeV. The last synchrotron, which uses superconducting magnets, feeds the clockwise and counter-clockwise collider rings alternately. Proton beams from the MEB are thus injected into the HEB in clockwise and counter-clockwise directions depending on the state of the its bipolar mode. The planes of the MEB and HEB are parallel to each other but are separated by 27.723 m vertically. The position of the MEB was chosen such that, in the plan view, the extraction straight for the clockwise (CW) transfer line is collinear with the HEB injection straight. For collider operations the normalized rms emittance of the beam is 0.7 π.mm.mrad. The transfer line design calls for transporting this beam with negligible emittance growth. The optical design was done by using the TRANSPORT code[1].

This paper presents the requirements and the rationale for the design of the two beam transfer lines connecting the MEB and the HEB. Extraction out of the MEB and on-axis injection into the HEB are described. Preliminary work on steering analysis and emittance growth are discussed.

II. BEAM EXTRACTION AND INJECTION

The extraction and injection sections of the CW and CCW lines are sufficiently similar that a common description can be given. Extraction out of the MEB is facilitated by means of five 1.43 m long fast kickers at 650 Gauss, located about 90° upstream of vertically bending Lambertson magnets. The kick results in a 31.7 mm horizontal displacement of the beam centroid from the nominal closed orbit of the MEB at the location of the first Lambertson magnet. A second Lambertson magnet and a c-magnet are then employed to bend the 200 GeV beam vertically by a total of 21.9 mrad so that the beam pipe of the transfer line clears the envelop of the closest MEB quadrupole. Injection into the HEB uses Lambertsons and a c-magnet similar to those of the extraction section as well as six 1 m long fast kickers at 500 Gauss. The injection Lambertsons and kickers are separated by a drift space of 70 m so that the beam is injected on-axis. At the exit end of the last Lambertson, the beam is on the plane of the HEB but separated from the nominal closed orbit by 28 mm and with an approach angle of 0.4 mrad. The kickers are then located at the point where the injection trajectory crosses the HEB nominal closed orbit and the kick removes the residual angle of 0.4 mrad. The extraction and injection Lambertsons are located in dispersionless regions.

	CW	CCW	Max. Strength [Length]
Length (m)	850	2200	-
Dipoles	4	17	9 T.m [5.8 and 6.5 m]
Quadrupoles	26	53	41 T.m/m [1.5 m]
Lambertsons	4	4	5.6 T.m [5.1 m]
C-magnets	2	2	3.4 T.m [2.7 m]
Extr. Kickers	5	5	0.09 T.m [1.43 m]
Inj. Kickers	6	6	0.05 T.m [1 m]
Trim Dipoles	28	54	0.3 T.m [1 m]
Trim Quads	4	8	6 T.m/m [0.5 m]
BPMs	34	59	[0.25 m]
BLMs	23	50	-

Table 1: Major design parameters of the CW and CCW transfer lines. The no. of trim dipoles is based on preliminary analysis.

III. COUNTER CLOCKWISE LINE

The substantial length of the CCW line allows the freedom to achieve optimal conditions for control of beam matching. The vertical bend center V1 (fig. 1) is composed of two unequal bends. The first four quads match the MEB beam into a 90° FODO with a half cell length of 51.5 m which forms the main transport optics. The position and strength of the second bend in V1 was chosen to provide achromaticity. The vertical

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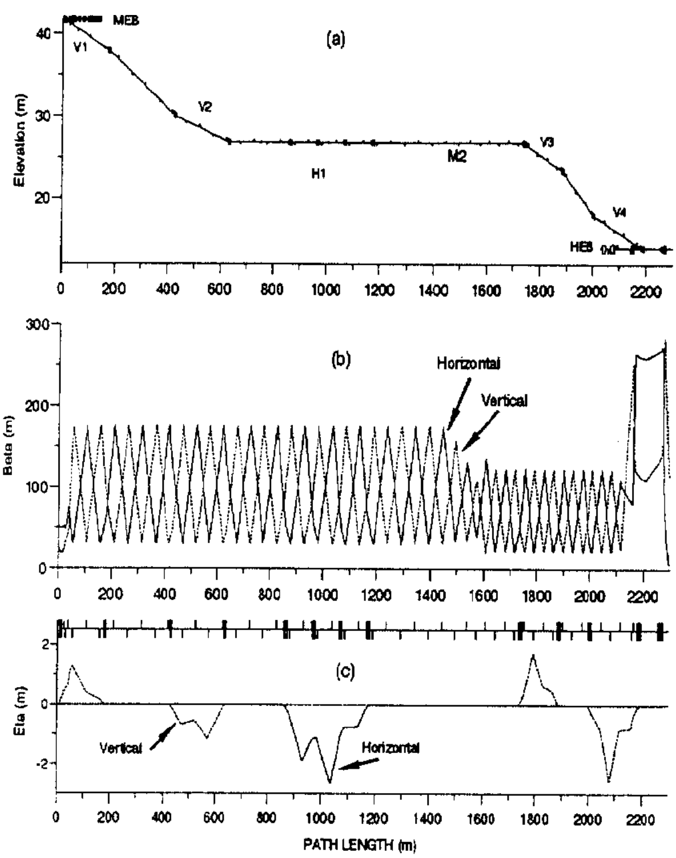

Fig. 1. Layout and lattice functions of the CCW line.

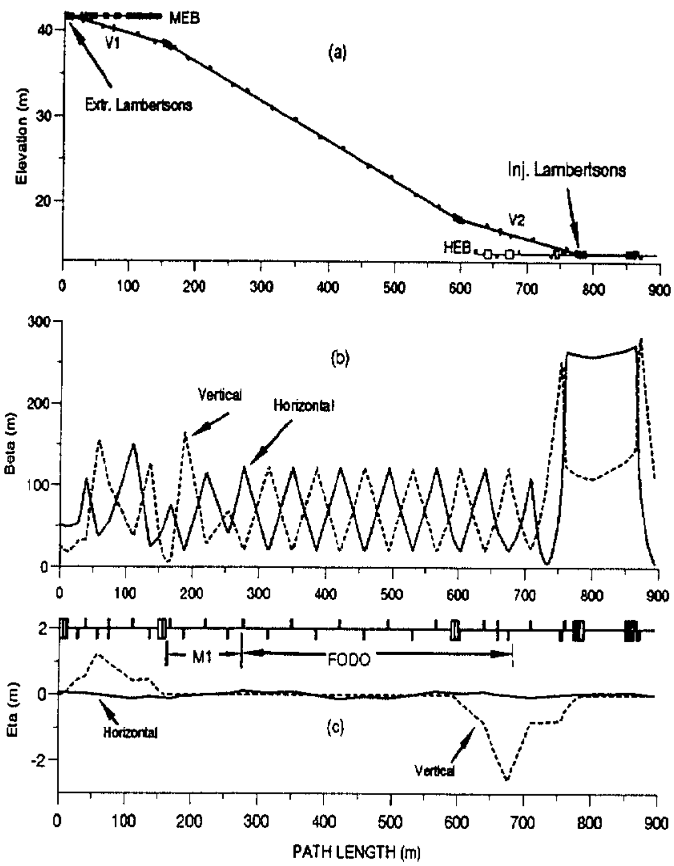

Fig. 2. Layout and lattice functions of the CW line.

bend centers V2 and V3 are symmetric each consisting of two groups of dipoles of equal strength separated by -I[2]. V2 brings the beam into a trajectory that is parallel to the planes of the synchrotrons so that an 83.5 mrad horizontal bend H1 can be implemented without coupling to the vertical plane. H1 consists of four equally spaced groups of identical dipoles embedded within the 51.5 m FODO and spanning a phase advance of $3\pi/2$. This optical arrangement can be viewed as two interlaced -I transformers. The FODO structure and the four equal bends ensure that H1 is achromatic. A set of four quadrupoles (M2) is used to match the 51.5 m FODO to a 36.2 m 90° FODO. The last vertical bend V4 consists of dipoles and Lambertson magnets at the upstream and down-stream ends, respectively. The intervening optics is made up of two cells of the 36.2 m FODO and three families of quads to provide an achromatic match into the HEB.

Since M2 is located in a dispersionless region, α and β matching can be controlled without affecting the dispersion. The modular nature of the 90° FODOs provide dispersion control with pairs of corrector quads on a common power supply. The quads in each pair are located -I apart - one inside any of the symmetric bends and one outside[2]. This scheme is illustrated in the example of fig. 3 where it has been used to correct for hypothetical input dispersions of $\eta_x=\eta_y=0.7$ m. The perturbations to β and α are confined to the -I region and the corrector quad strengths do not exceed 20% of the main FODO quads.

IV. CLOCKWISE LINE

The main features of the CW line are the 36.2 m FODO transport optics and the bend centers V1 and V2, each of which is individually achromatic (fig. 2). The positions and strengths of the dipoles was dictated by floor layout constraints as well as by a desire to include a portion of the 90° FODO inside V2. The latter allows for one orthogonal control of the vertical dispersion where two trim quadrupoles -I apart may be adjusted in phase as in the case of the CCW line. This line, however, does not have any options for controlling the horizontal dispersion. Since the expected rms $\delta p/p=5\times10^{-5}$ the effect of dispersion mismatch on emittance dilution is negligible[3].

V. BEAM STEERING

Monte calro calculations of beam steering were used to determine beam position monitor locations as well as corrector magnet strengths. Dipole excitation error (rms) of 5×10^{-4}, quadrupole misalignment error of 0.5 mm and initial beam trajectory errors of 0.5 mm and 0.01 mrad were assumed. With the number of BPMs and steering dipoles indicated in Table 1, the maximum beam excursion was about 2 mm in both planes. Orthogonal x,x' and y,y' corrector dipoles in the transfer lines together with the HEB ring BPMs will be used for final steering into the HEB. The precision of correcting for such systematic errors will be limited by the resolution of the BPMs.

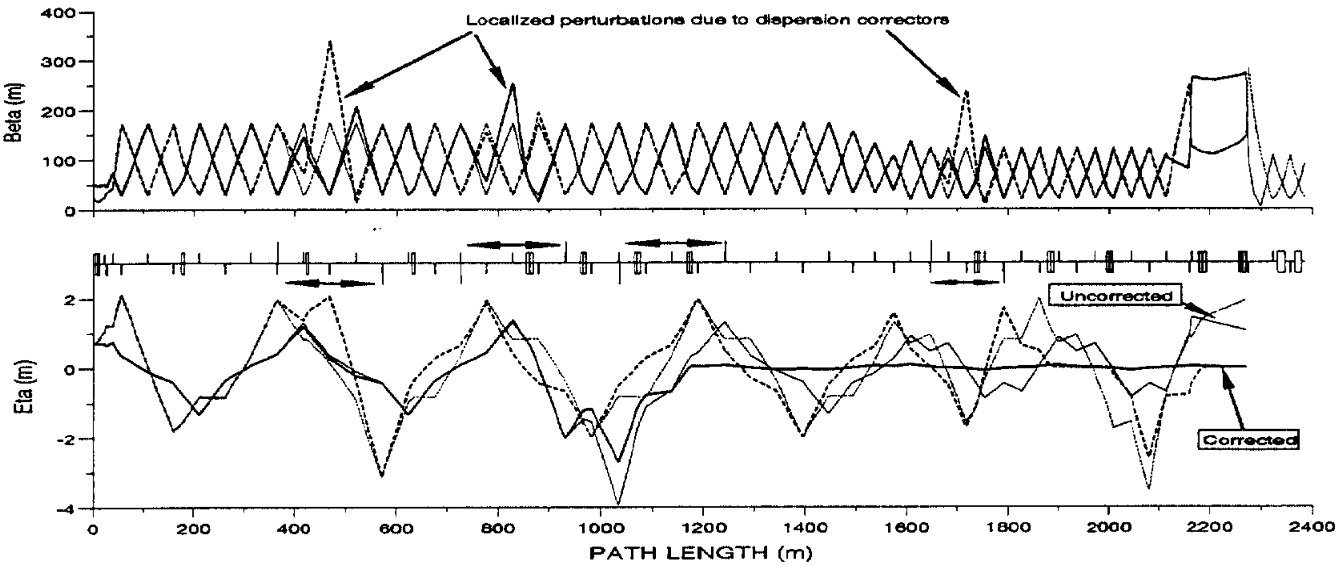

Fig. 3. Dispersion correction using the -I concept. Paired corrector quadrupoles (F and D) are indicated by the arrows.

VI. EMITTANCE DILUTION

Having corrected for systematic quadrupole alignment errors, etc., the most important remaining source of steering errors is random time dependent (pulse to pulse) variations of dipole fields. If the relative field fluctuations ($\Delta B/B$) within each achromat can be made the same by putting the dipoles on a common power supply, it can be shown that, to first order, there is no net injection steering error. In practice this is most easily implementable in the symmetric bend centers V2, H1 and V3 in the CCW line where the dipoles in each achromat are identical in length and strength. Most of the steering errors in both transfer lines are, therefore, expected to come from the kickers and Lambertson magnets as well as from the dipoles in the first and last vertical achromats. The resulting emittance dilution[3] can be shown to be dependent only on the floor layout constraints and the betatron amplitudes at the MEB extraction and HEB injection regions. The expected contributions to emittance dilution, based on attainable power supply stability, are listed in Table 2. For comparison, the allowed growth in emittance due to the MEB and transfer lines combined is about 0.1 π.mm.mrad[4]. It is evident that this requirement cannot be met without the use of transverse dampers in the HEB. Systematic or random quadrupole gradient errors lead to mismatches in α and β with attendant emittance growth[3,7]. The effect of sextupole field errors of $1\text{X}10^{-3}$ at 12 mm from the center of the dipole gaps was simulated by using the program TURTLE[5]. These are included in table 2.

Source	$\Delta B/B$ (rms) (Stability)	$\Delta\epsilon_{normal}$ (π..mm.mrad)
Extr. Kickers	$1\text{X}10^{-2}$	0.01
Inj. Kickerrs	$1\text{X}10^{-2}$	0.09
Lambertsons/Dipoles	$1\text{X}10^{-4}$	0.12
Quad Grad.	$1\text{X}10^{-3}$	0.005
Sextupole Errors	$1\text{X}10^{-3}$ @12 mm	0.005

Table 2: Expected addition to normalized emittance. The first three entries are correctable with transverse dampers.

VII. CONCLUSION

The regular FODO optics of the transport system is expected to greatly simplify the interpretation of beam diagnostics data as well as the implementation of transfer matrix measurement and correction schemes[6]. In the case of the CCW line the FODO structures enhance tunability by providing independent and mutually exclusive controls over the dispersion and the transverse lattice functions. In view of the relatively large beam size (σ_x=1 mm) and the small (40 mm) beam pipe aperture of the HEB, on-axis injection offers simplicity and full use of machine aperture.

While the strength and position of all major dipoles is fixed, the lattice design is periodically updated to meet on-going design changes in the MEB and the HEB without compromising the regular optical structure. Further investigations are planned to determine ways of relaxing the specifications on dipole excitation errors and power supply stability. The implications of kicker failures are yet to be fully understood and safeguards need to be incorporated into the overall design.

VIII. REFERENCES

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