HEB to Superconducting Super Collider Transfer Lines

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Abstract

We present here an optics design for a beam transport system which will be used to inject 2 TeV proton beam from the High Energy Booster into the Superconducting Super Collider. The main design issues are the use of conventional magnets for constructing this high energy beamline and maintenance of small beam transverse emittance during the transfer process. Effects of various errors have been investigated in detail, then tolerances for errors are given. With the design criterion and beam position correction scheme proposed, proton beam transverse emittance dilution is expected to be less than five percent.

I. Introduction

The HEB is the last synchrotron of the three injector synchrotrons in cascade of the injection systems for the two Superconducting Super Colliders. The devices that eject proton beam from the HEB for injection both clockwise and countclockwise into the bottom and top colliders are located within the west long straight section of the HEB. The collider injections take place in the west utility straight sections which are located directly under the HEB west long straight section. The elevation separation between the lower collider and the HEB is 14m which is determined by a radiation shielding requirement. In SSCL Site-Specific Conceptual Design[1], the two beam lines joining HEB and colliders include warm septum magnets, pulse kicker magnets at both ends of the lines, superconducting major vertical bending magnets, and quadrupoles.

To eliminate troubles of transfer line superconducting magnet quenches, this design makes use of warm magnets only. The total length of each of these lines, determined by geometric boundaries, is about 631m. The use of low field conventional bends requires additional effort to find an optical structure to accomplish matching of optical parameters, while keeping reasonable β and dispersion function amplitudes through the line.

Another main issue of this transfer system design is to preserve the small proton beam transverse emittance during ejection, transfer, and injection which is important for obtaining high collider luminosity. Effects of magnet misalignment and various field errors to emittance dilution have been investigated to determine tolerances for errors and magnet design criterion. A beam position correction system is also proposed to reduce dilution effects due to beam centroid displacement at injection region.

II. Beam Optics and General Layout

The layout of the ejection, beamlines, and injection devices is shown in Fig.1. The HEB ejection kickers and the Collider injection kickers provide horizontal shifting of the beam orbit. The beamline magnets bend beam vertically only.

Each of these two beamlines consists of two quasi achromatic bending sections with inverse deflecting direction. The short straight section between them provides the flexibility of optical parameter adjustments. The two lines are similar, with the exception of 0.2m difference of middle straight section length, and slightly different operating fields to accommodate different elevation levels of the two colliders. Similarity of design is important in maintaining ease of operation.

The upper limits of bending field and quadrupole field gradient adopted here are 1.81T and 30T/m, respectively, for 4cm full aperture magnet design. About 50% of beam line length is occupied by bending magnets. The requirements to leave space for crossing of one line with top collider, as well as the crossing of two lines push part of the bending magnets further away from both ends of the beamline. Both the low bending field and space requirements demand the increasing of total bending angle while leaving less space and more difficulty to accomplish phase space and dispersion matching and keeping amplitudes of β and dispersion function small. The optical functions of the beamline are shown in Fig.2. The maximum β function

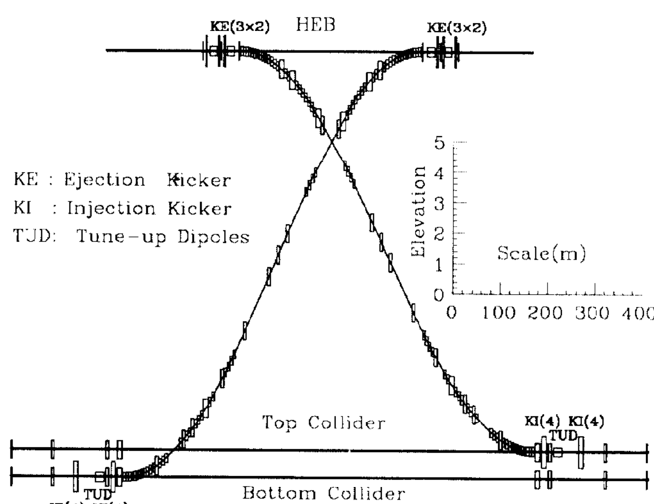

Fig.1 HEB--Collider Transfer Layout

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amplitude is 425m, and dispersion is compressed to less than 2m everywhere.

III. Effects of Magnet Misalignment and Field Errors

There are two major concerns caused by various errors for this transfer system: aperture requirement, and beam transverse emittance dilution. Since high bending field and quadrupole gradient have to be used, small magnet aperture is desired. The 2 TeV proton beam has a very small transverse emittance: $4.7\times10^{-10}\pi$ m rad. Beam dimensions have little influence on aperture consideration. Tolerances of systematic magnet alignment and magnet field errors are set to allow beam to pass the beamline without position corrections. The more critical tolerances come from the requirement to preserve beam transverse emittance. Small position and angular errors to the ideal collider closed orbit will cause large emittance dilution if they are not precisely corrected. Statistical bending field errors and quadrupole gradient errors are responsible for position mismatching and optical parameters mismatching which will inevitably lead to emittance dilution. Dilution effects due to centroid displacement, mismatching of β, and dispersion functions at injection in a circulating accelerator are well described by M. J. Syphers[2]. For injection position mismatching one has:

$$F_x \sim \frac{\sigma^2}{\sigma_0^2} = 1 + \frac{1}{2}\left[\frac{\Delta X_{eq}}{\sigma_0}\right]^2 \qquad (1)$$

where

$$\Delta X_{eq} = \sqrt{(\Delta X)^2 + [\beta\Delta X' + \alpha\Delta X]^2}$$

The dilution factor is defined as the ratio of phase space areas containing 95% of the beam particles, after and before dilution occurs. Since the transverse beam rms size σ_0 is about 0.2-0.3mm, ΔX_{eq} from Eqt. (1), should be less than 0.1 mm if dilution less than 5% is required.

A program code is developed for a quick and effective evaluation of all the relevant quantities at injection point caused by various errors of the beam transport system. The program can perform a fixed error calculation as well as multi-trial simulations with normally distributed random errors of a given standard deviation for all magnet misalignment, field, gradient errors, and initial beam conditions. One can then decide what tolerances for errors should be set, and what kind of position correction scheme should be used to reduce the aperture requirement and preserve beam emittance.

Table 1. sums up the resulting error tolerances from analysis and simulation[3], which is required for either free pass of 30mm beamline aperture without position corrections, or emittance dilution of less than 5%.

Table 1. Tolerances for various errors

Error Type	Tolerances	Required as
Q Trans. shift	0.2 mm	Aperture
B Rot. about Z	1.0 mrad	"
$\Delta B/B$(systematic)	0.001	"
Q gradient	0.002	Emittance
$\Delta B/B$ (regulation)	5×10^{-5}	"
Kickers $\Delta B/B$	0.003	"

In addition to these error tolerances, a beam position correction system must be included to provide precise matching of the injected beam trajectory to collider closed orbit.

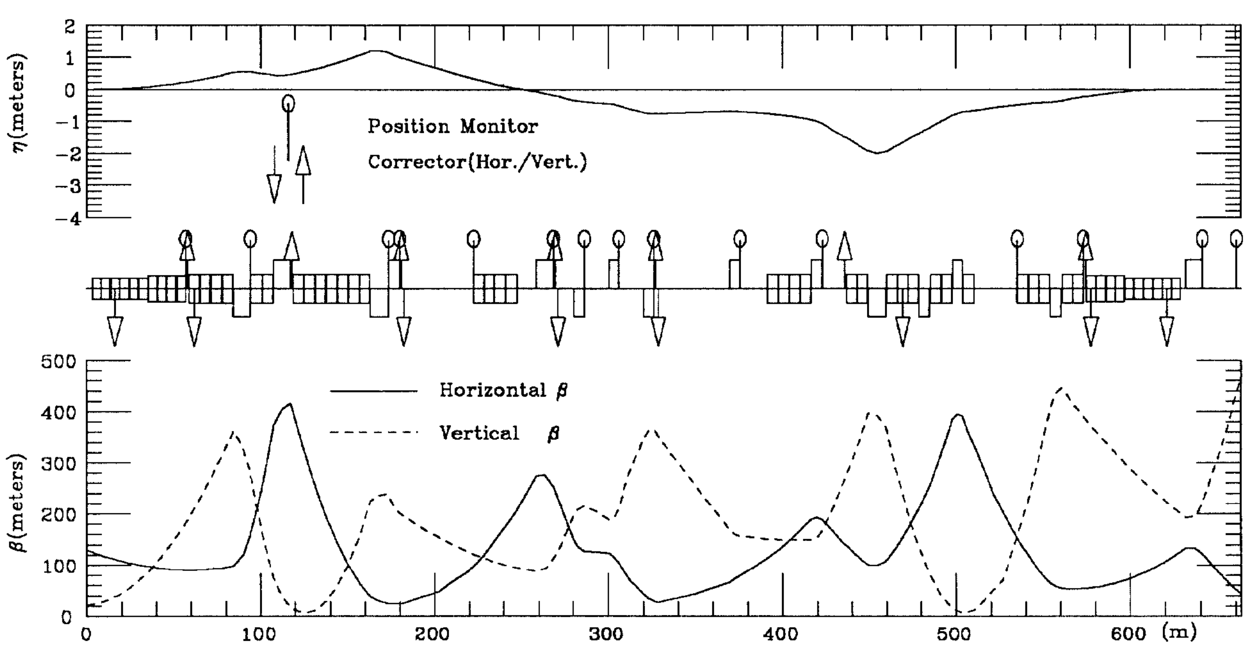

Fig.2 Beam Line Amplitude, Dispersion Functions and Position Correction Scheme

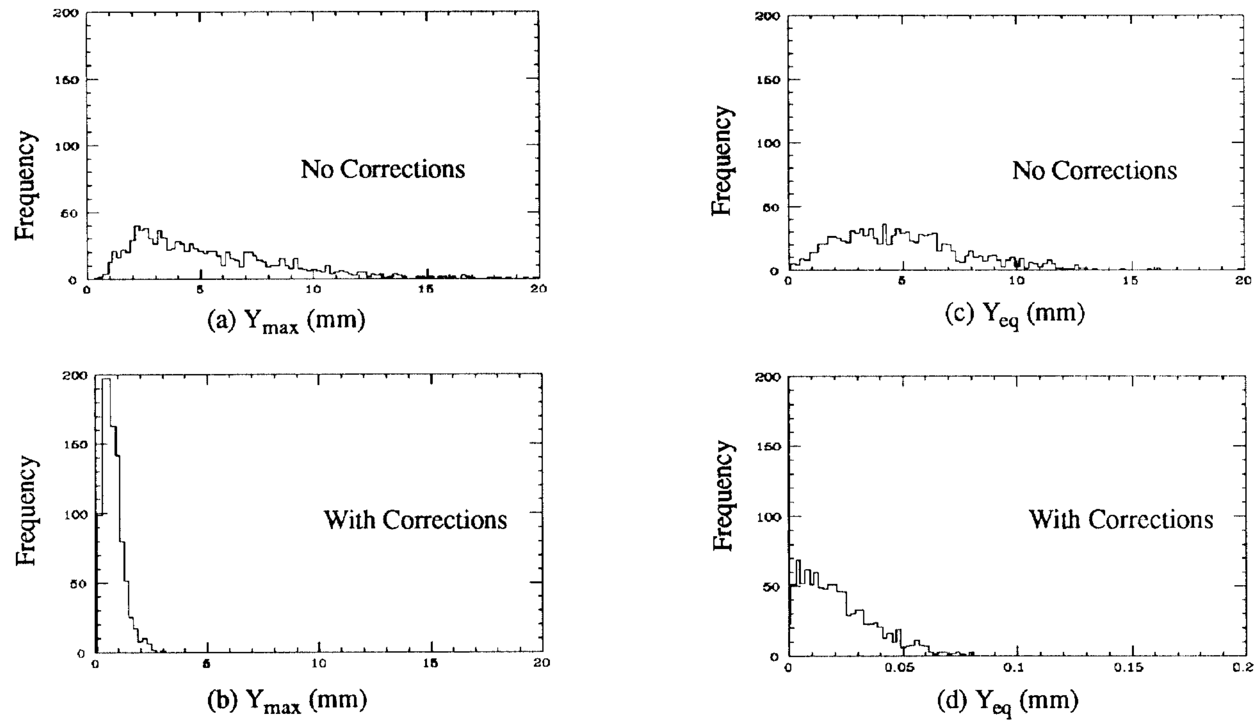

Fig.3 Distributions of maximum displacement and Y_{eq} before & after corrections, for 1000 trials with errors listed in Tab.1 (aperture), and initial rms Δy=0.8 mm, $\Delta y'$=12 μrad

IV. Beam Position Correction Scheme

A proposed beam position correction scheme is shown in Fig.2. The correction scheme has two stages: in most of the line, each corrector takes care of the position errors read from the monitors between itself and the next corrector. The quantity $\Sigma(X_i+\Delta X_i)^2$ is minimized to obtain needed corrector strength. Here X_i is the position error before correction and ΔX_i is the displacement produced by the corrector at the ith position monitor. At the end of beam line there are two pairs of correctors, one for each transverse direction. Position errors are read from two monitors which are located in a utility straight section of the collider. The correction is then applied to both position and angular deviation of beam centroid to collider closed orbit. The strength of these two correctors are obtained by minimizing the quantity $\Sigma\,(X_i+\Delta X_{1i}+\Delta X_{2i})^2$.

Since the required emittance dilution is small, the two monitors located in the straight section between collider quadrupole QU3 and QU4 require a position resolution of 10 μm. Another pair of monitors located downstream of kickers will provide horizontal position errors for kicker amplitude fine adjustment. All the correctors, except kickers, are out of colliders; therefore, beamline position corrections will not interfere with circulating beam.

A number of simulations of correction process have been made in order to find a scheme which makes use of fewer correctors, lower correcting strengths and desired correction results.

Fig.3 depicts the correction results for 1000 trials simulation in vertical direction. The maximum vertical beam centroid displacement along the beamline, Y_{max}, is less than 2.5mm after corrections and the quantity Y_{eq} in Eqt. (1), is less than 0.07mm at end of beamline, which corresponds to a dilution factor of 1.03.

V. Conclusion

The use of conventional magnets to construct the beam transfer lines between the two superconducting proton machines with the imposed geometry is viable. Beam transverse emittance dilution will also be under control with proper error tolerances set and a precise position correction scheme.

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VI. References

[1] *Site-Specific Conceptual Design*, SSCL-SR-1056, p.119 1990.

[2] M. J. Syphers, *Injection Mismatch and Phase Space Dilution*, FN-458, 1987.

[3] F. Wang and R. Schailey, *Design Issues for the HEB-Collider Transport System*, SSCL ADOD- 017B, 1991.