Beam Optics of LEB-MEB Transfer Line for Superconducting Super Collider

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Abstract

The beam optics of the transfer line between the Low Energy Booster (LEB) and the Medium Energy Booster (MEB) at the Superconducting Super Collider Laboratory is presented. The 12 GeV/c proton beam is extracted from the LEB and injected into the MEB at strictly defined extraction and injection points. The beamline has a high flexibility for β and η function matchings. Effects of various errors are studied, and a beam position correction scheme is proposed.

I. INTRODUCTION

The LEB-MEB transfer line at the Superconducting Super collider Laboratory transports 12 GeV/c proton beam from the Low Energy Booster (LEB) to the Medium Energy Booster (MEB). The two boosters are at different elevations, and the extraction and injection points on these two rings are strictly defined. The tune point of the LEB may vary to a certain extent, and six tune points are selected to represent the possible range of tuning. The lattice functions of these two boosters may also vary because of various errors in these two boosters. Therefore, the optics design of the LEB-MEB transfer line must consider the basic optical problems, such as beam centroid matching, β function matching, and η function matching.

The misalignments and field errors of the transfer line magnets are sources of beam centroid, β function and η function mismatchings, all of which can cause emittance growth. In order to obtain a high luminosity in the collider, the emittance growth has to be minimized. The effects of different kinds of errors along the transfer line are studied, and a beam position correction scheme is proposed.

Relating to the transfer line, there is also an absorber (beam dump) line, which transports the proton beam extracted from the LEB to the absorber during the LEB commissioning. This line will not be discussed in this paper.

II. LAYOUT AND MATCHINGS

The elevation difference between the LEB extraction point and the MEB injection point is about 0.46 m and the total length from the extraction point to the injection point is about 249 m. The general layout of this transfer line is shown in Figure 1, including the elevation view and plan view.

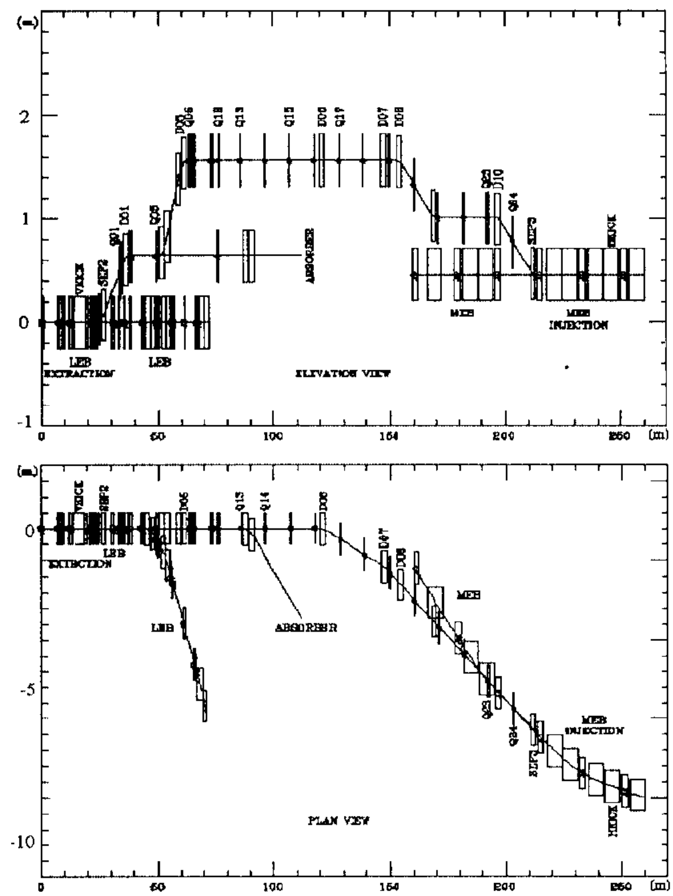

Figure 1. Layout of the LEB-MEB transfer line.

The LEB extraction straight, which consists of a vertical kicker (VKICK, Figure 1), five bump magnets and two septum magnets (SEP1 and SEP2), extracts the beam vertically from the LEB. The MEB injection straight, including a Lambertson septum magnet (SEP3) and a horizontal kicker (HKICK), injects the beam into the MEB at the injection point.

The transfer line itself has ten dipoles (each 2 m in length) and twenty-four quadrupoles (each 0.5 m in length) to transport the beam from the LEB to the MEB, and complete the beam centroid matching, β function matching and η function matching. The twenty-four quadrupoles are separated into three sections, an η_y matching section

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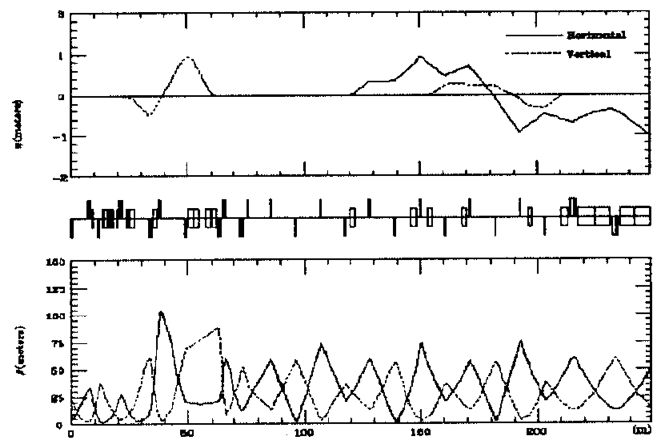

Figure 2. β and η functions of the LEB-MEB transfer line.

(five quadrupoles, Q01 through Q05), a β matching section (seven quadrupoles, Q06 through Q12), and a FODO section (twelve quadrupoles, Q13 through Q24). The FODO section also plays a role of η function matching while lattice functions of these two boosters vary.

A. *Centroid Matching*

The layout is the result of the beam centroid matching. This matching is completed by the ten dipoles with suitable positions and bending angles. The first five vertical dipoles (D01 through D05, Figure 1) separate the transfer line from the LEB ring entirely in the vertical direction, and raise the beam center line to an elevation of about 1.57m. On the MEB side, the last three vertical dipoles (D08 through D10) and the Lambertson septum magnet (SEP3) lower the beam line to the MEB elevation, and make the beam move in the horizontal plane.

The centroid matching in the horizontal plane is mainly accomplished by the two horizontal dipoles (D06 and D07). By adjusting the positions of these two dipoles and setting their total bending angle to 4.59^0, the beam after passing through these two dipoles has the required position and direction, and therefore can be precisely injected into the MEB by the horizontal kicker.

B. *β Function Matching*

The required β and η matchings of the transfer line are performed by adjusting the parameters of the dipoles and quadrupoles. The β and η functions along the transfer line for one LEB tune point (TUNE E) are shown in Figure 2. The β functions have a maximum value of 103 m, and in most of the transfer line are only 75 m or less. This means that the transfer line has a low sensitivity to errors in the magnets.

The β matching is performed by the β matching section of seven quadrupoles, but because three pairs of adjacent quadrupoles are powered in series, the seven quadrupoles have just four adjustable quadrupole components necessary to complete the β_x, β_y, α_x and α_y matchings. In addition, the β function variations due to the errors of these two boosters are also considered. The analysis results show that this section can complete the matching for 20% β variation of the LEB and 10% β variation of the MEB, as required.

Since this β matching section is located in the region where the η functions are zero, the β function matching has no effect on the η functions.

The FODO section, downstream of the β matching section, transports the beam for more than 120 m, through a set of dipoles, to the MEB injection straight. Because of the space limitation in the transfer line, the parameters of the FODO array are slightly different from the MEB lattice, and a small but unimportant β function beating within this section appears.

C. *η Function Matching*

The η functions in the horizontal plane are η_x=η_x'=0 at the LEB extraction point and η_x=-1.063 m, η_x'=-0.049 at the injection point (Figure 2). The η_x function matching is completed by adjusting the positions and relative bending angles of the two horizontal dipoles (D06 and D07), while meeting the requirement of the horizontal centroid matching.

If the horizontal η functions of these two boosters vary, the matching can be regained by adjusting the gradients of one or two pairs of quadrupoles in the FODO section in an orthogonal way [1]. The two quadrupoles of each pair are separated by 180^0 phase advance and the transfer matrix between them is -I. For η_x matching, a phase advance approximate to (n+1/2) x 180^0 between this pair and MEB injection point is required; and for η_x' matching, a phase advance approximate to n x 180^0 is required. To achieve matching, the η_x functions at the positions of the paired quadrupoles should be different. This occurs if a horizontal dipole is located between the paired quadrupoles. In the LEB-MEB transfer line, quadrupoles Q15 and Q19 are chosen for η_x matching, Q13 and Q17 for η_x'. The gradient adjustment for the two paired quadrupoles is of opposite sign. A gradient adjustment of about 5% is needed for an LEB horizontal dispersion variation of $\Delta\eta_x$=0.1 m.

In the vertical plane, this transfer line is an achromatic transport system. η_y matching is performed by the η_y matching section (Q01 through Q05). Because multiple power supplies are used, this section has only three adjustable components, two for η_y and η_y' matchings, and the other for producing a horizontal waist. If the η_y functions of these two boosters vary, the rematching can also be achieved by adjusting the gradients of one or two pairs of quadrupoles in the FODO section, as discussed for η_x matching. Obviously, this transfer line has a high flexibility to match different conditions.

The beam optics is calculated with program TRANSPORT [2].

III. ERROR EFFECTS AND POSITION CORRECTION SCHEME

The magnet misalignments and field errors in the transfer line cause beam centroid, β function, and η function mismatchings. The tolerance to the misalignments and field errors are mainly constrained by two factors, one is the limited magnet aperture, and the other is the allowed emittance growth. The latter is more stringent, as the allowed emittance growth is only a few percent.

The transverse emittance dilution due to mismatching has been studied in detail [3]. For beam centroid mismatching Δx and Δx', the transverse emittance dilution factor

$$F_x \sim \frac{\epsilon}{\epsilon_0} = 1 + \frac{1}{2}[\frac{\Delta x_{eq}}{\sigma_0}]^2, \qquad (1)$$

where

$$\Delta x_{eq} = \sqrt{(\Delta x)^2 + (\beta \Delta x' + \alpha \Delta x)^2}. \qquad (2)$$

The rms transverse beam sizes σ_0 at the MEB injection point are 1.5 mm and 0.8 mm in the horizontal and vertical planes, respectively. If an emittance growth of less than 1% is required for centroid mismatching, Δx_{eq} should not exceed 0.1 mm. In practice, beam position corrections are necessary. In order to study the effects of various errors on the beam centroid, β and η, and to develop a position correction scheme, a program, EAC, has been developed [4] and used in the LEB-MEB transfer line design. Errors causing beam centroid mismatching can be divided into two types. One type includes the magnet field instabilities, and the other includes all the systematic errors, such as dipole rotations and field setting errors, quadrupole transverse displacements, centroid displacement and angular deviation of the LEB extracted beam and so on.

An analysis has been made on the beam centroid mismatching caused by the field instabilities. The fractional errors assumed in the analysis are as follows: 1x10^{-2} for LEB extraction and MEB injection kickers, 2x10^{-3} and 1x10^{-3} for the first and second LEB extraction septum magnets respectively, (1-2)x10^{-4} for the MEB injection Lambertson septum magnet and the ten dipoles of the transfer line itself. The analysis shows that the centroid mismatching in the vertical plane Δy_{eq}=1.0 mm, if the field errors of the injection septum magnet and the ten dipoles are 1x10^{-4}; and Δy_{eq}=1.5 mm, if the field errors are 2x10^{-4}. These mismatchings correspond to 76% and 167% emittance growths. An injection damping system in the MEB is needed to correct this effect.

As for the beam centroid mismatching due to systematic errors (say, a dipole rotation angle of 1.0 mrad, a field setting error of 5x10^{-4}, a quadrupole transverse displacement of 0.25 mm, an LEB extracted beam centroid displacement of 0.5 mm, and a beam angular deviation of 0.1 mrad), it can be corrected by using a correction scheme, consisting of correctors and beam position monitors in the transfer line. The scheme is designed through statistical simulation; that is, randomly choosing field errors, then calculating the necessary corrector strengths and the centroid displacement along the transfer line. One thousand seeds are normally used in the simulation. Figure 3 shows a correction scheme for the LEB-MEB transfer line, which uses fewer correctors and lower corrector strengths, and has an optimal correction result. In most of the transfer line, "one (corrector) to one (downstream monitor)" correction mode is used. It means that each corrector corrects the beam centroid displacement where the monitor is located. But at the end of the transfer line, "two to two" correction mode needs to be used normally. This mode corrects both beam centroid displacement and angular deviation. After correction, the maximum transverse centroid displacement along the transfer line is about 2.1 mm; and at the end of the transfer line Δx_{eq} and Δy_{eq} are less than 0.02 mm, corresponding to an emittance growth of less than 0.1%. The maximum corrector strength required is less than 0.7 mrad.

The β function and η function mismatchings caused by rms quadrupole gradient error of 1x10^{-3} will lead to an emittance growth of less than 0.1%.

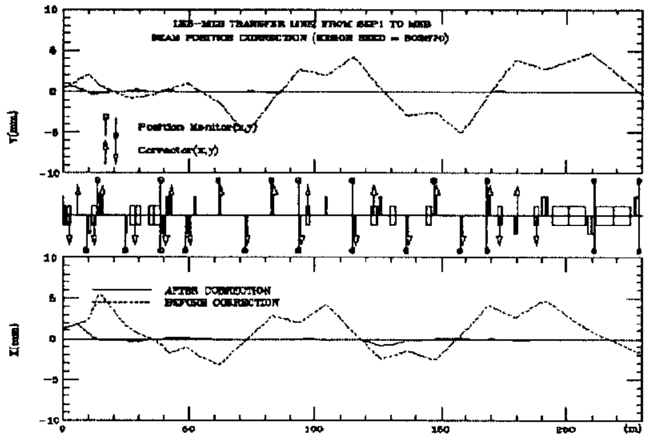

Figure 3. Position correction scheme.

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