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Beam Position Mismatching and Correction of LEB - MEB Transfer Line

N. Mao, R. Gerig, and J. McGill
Superconducting Super Collider Laboratory
2550 Beckleymeade Ave.
Dallas, TX 75237

K. Brown
Stanford Linear Accelerator Center
Stanford University
Stanford, CA 94309

Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309

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Abstract

The LEB–MEB beam transfer line for the Superconducting Super Collider has ten dipoles, twenty four quadrupoles and three septum magnets. The effect of magnet misalignments and field errors on the beam position mismatching and emittance growth is analyzed statistically and a beam position correction scheme is given. The beam position correction of the related LEB absorber line is also discussed.

1.0 INTRODUCTION

The LEB–MEB beam transfer line[1] at the Superconducting Super Collider Laboratory transports 12 GeV/c proton beam from the Low Energy Booster (LEB) to the Medium Energy Booster (MEB). This transfer line has 10 dipoles (STR1, STR2, STR3, BNH2, BNH1, SEPC, SEPB and SEPA), 24 quadrupoles (QU1, QF1, QU2, QFM1,...,QFM4, Q13, Q12,..., and Q02) and 3 septum magnets (SEP1, SEP2 and SEP3), as shown in Figures 1 and 2. The β and η functions of the transfer line are shown in Figure 3.

The magnet misalignments and field errors in the transfer line cause beam centroid position, β function, and η function mismatchings. The tolerance to the misalignments and field errors is 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. If an emittance growth of less than 1% is required, the position mismatching, *i.e.*, the equivalent position displacement at the MEB injection point should be as small as 0.1 mm. In practice, beam position correction is necessary.

There are two types of errors causing beam position mismatching. One includes all the systematic errors such as magnet misalignments, field setting errors, the centroid position displacement and angular deviation of the LEB extracted beam. And the other is the magnetic field instability. In this paper only the first type of errors will be addressed, as the second has been studied in detail in other papers.[1,2]

In order to study the effect of various errors on the beam position mismatching and emittance dilution, and to develop a position correction scheme, a statistical method and the corresponding code EAC[3] are used. EAC independently analyses the effect of errors and develops the position correction scheme on the basis of the linear optics design using the code TRANSPORT.[4] EAC also has a post processing package to generate various types of graphics, such as beam line geometrical layouts, plots of β and η functions, beam envelopes, and so on, as shown in Figures 1–3.

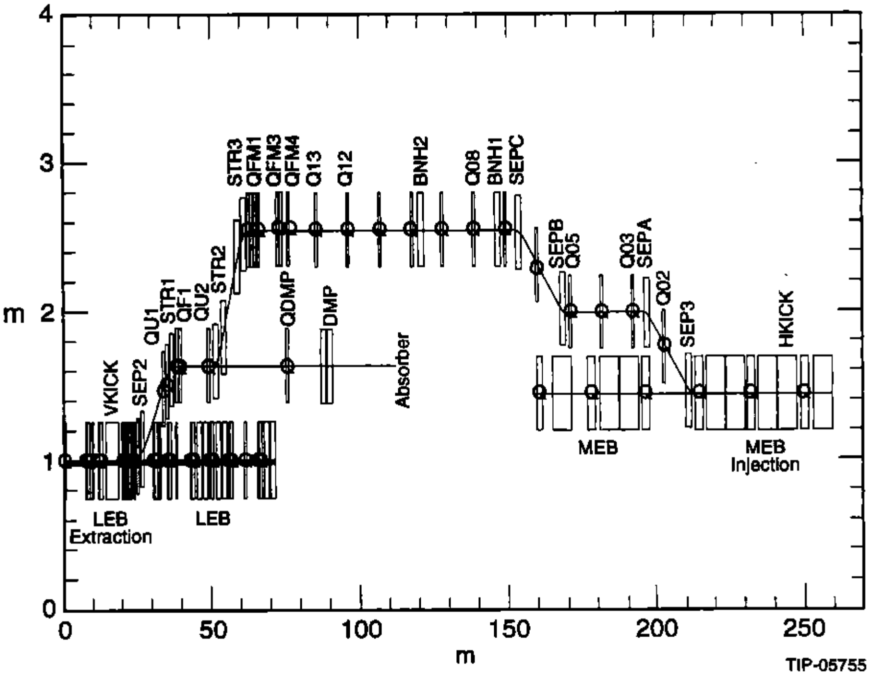

Figure 1. Layout of the LEB–MEB Transfer Line (Elevation View, LEB630 and LEB917).

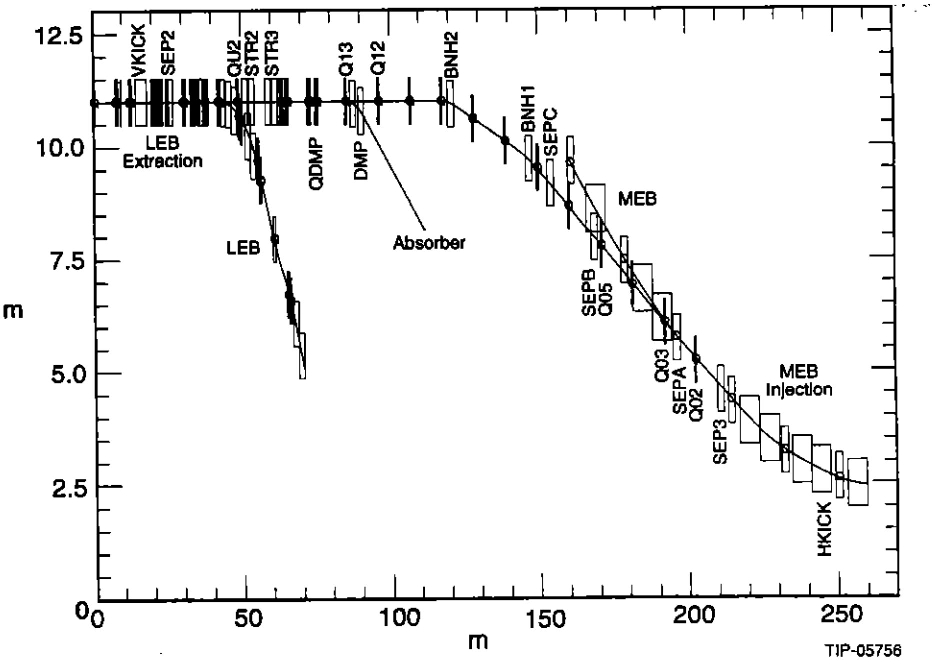

Figure 2. Layout of the LEB–MEB Transfer Line (Plan View, LEB630 and LEB917).

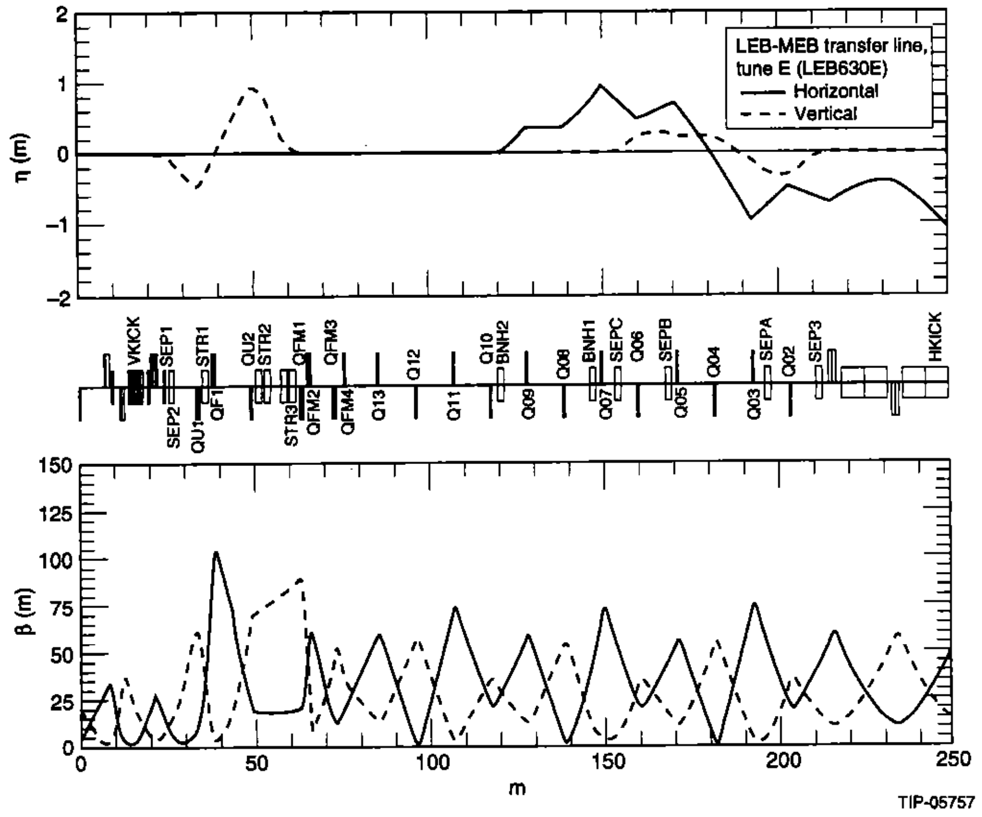

Figure 3. β and η Functions of the LEB–MEB Transfer Line (LEB630E).

2.0 EFFECT OF SYSTEMATIC ERRORS ON BEAM POSITION MISMATCHING

The rms values of the systematic errors of the LEB–MEB transfer line that cause the beam centroid position displacements and mismatching are listed as follows:

1. Quadrupole transverse displacements DIS(x) = DIS(y) = 0.25 mm, rotation angle about the z axis ROT(z) = 1.0 mrad;
2. Dipole rotation angle about the z axis ROT(z) = 1.0 mrad, field error $\Delta B/B = 1 \times 10^{-3}$;
3. LEB extracted beam position errors $\Delta x = \Delta y = 0.5$ mm, angular deviations $\Delta x' = \Delta y' = 0.1$ mrad.

In the statistical analysis of the error effect, 1000 seeds are randomly selected and the corresponding beam position displacements along the beam transfer line are simulated. Figure 4 gives an example of the beam position displacements (dash lines) along the transfer line in both horizontal (x) and vertical (y) planes, the error seed selected here is 1170126. Figure 4 shows that the maximum displacement is larger than 10 mm. Obviously, a beam position correction scheme is absolutely necessary for errors of this magnitude.

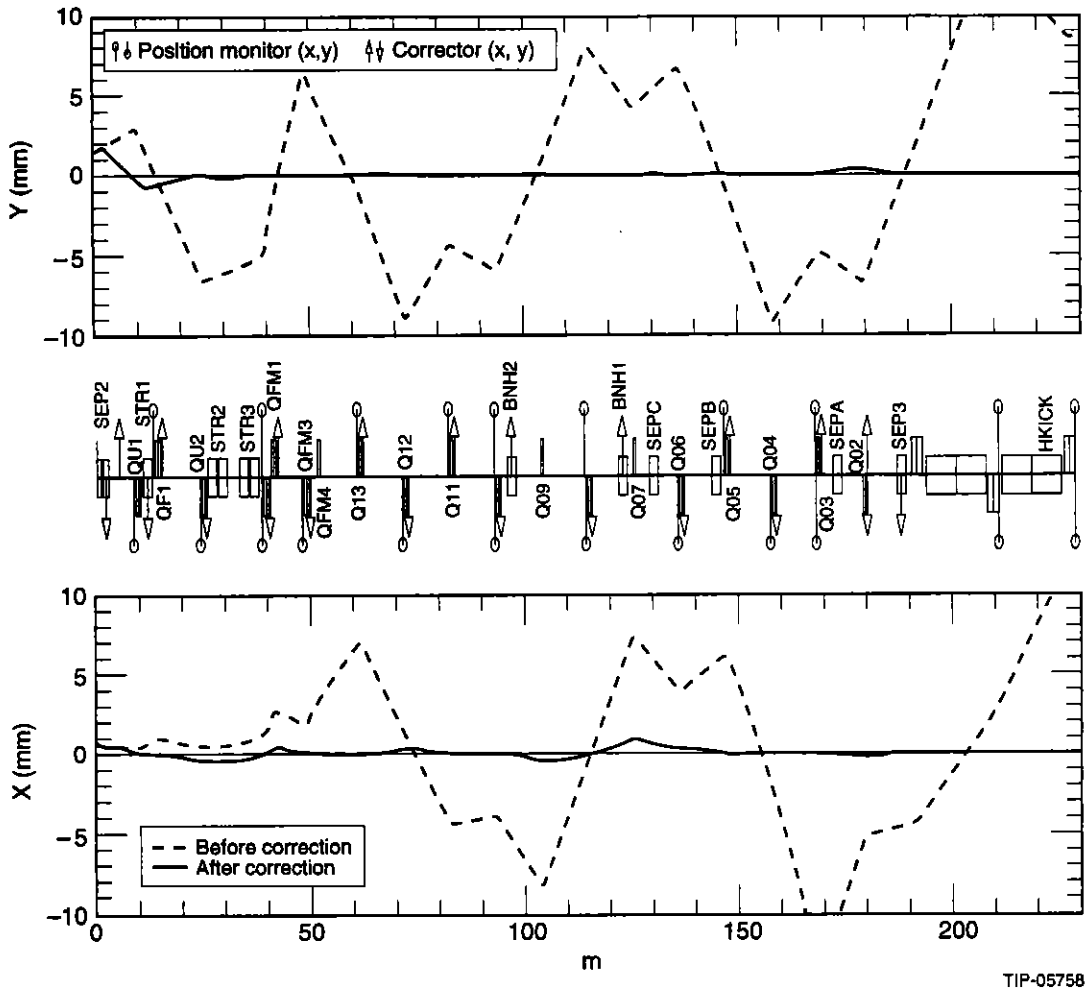

Figure 4. Beam Position Correction Scheme of the LEB–MEB Transfer Line (LEB634E10).

3.0 BEAM POSITION CORRECTION SCHEME

The transverse emittance dilution due to mismatching has been studied in detail.[5] For the beam centroid position and angular mismatchings (Δy and $\Delta y'$ at the MEB injection point, taking the vertical plane as an example), the dilution factor

$$F_y \sim \frac{\varepsilon}{\varepsilon_0} = 1 + \frac{1}{2} \times \left[\frac{\Delta y_{eq}}{\sigma_0} \right]^2 \qquad (1)$$

where

$$\Delta y_{eq} = \sqrt{\Delta y^2 + [\beta \Delta y' + \alpha \Delta y]^2} \quad .$$

For an MEB injection normalized emittance $\varepsilon_0 = 0.6\ \pi \times \text{mm} \times \text{mrad}$ (collide operation mode), the beam rms half width $\sigma_0 = 0.8$ mm. If an emittance growth of less than 1% is required, Δy_{eq} should be as small as 0.1 mm. As mentioned above, the beam position displacement caused by the systematic error may be larger than 10 mm, therefore a beam position correction scheme is needed to reduce the beam position displacement and control the emittance growth.

The proposed correction scheme consists of dipole correction magnets (correctors) and beam position monitors (BPMs). The scheme is designed through statistical simulation, that is, randomly choosing magnet misalignments and field errors, then calculating the necessary corrector strengths and the centroid displacement along the transfer line. One thousand seeds are normally selected in the simulation. In most of the transfer line, a "one (corrector) to one (downstream BPM)" correction mode is used. It means that each corrector corrects the beam centroid displacement where the BPM is located. But at the end of the transfer line, a "two-to-two" correction mode needs to be used. This mode corrects both beam centroid displacement and angular deviation.

Figure 4 shows a correction scheme for the LEB–MEB transfer line, which requires 14 BPMs and 17 correctors. Among these BPMs, there are ten single-direction BPMs (four for x direction and six for y direction) and four dual-direction BPMs (for both x and y directions). In addition to these BPMs, two dual-direction BPMs, located upstream and downstream of the MEB injection kicker (HKICK) in the MEB injection insert, are also used to give the beam position information for the transfer line position correction. Among these correctors, eight adjust the beam position in the horizontal plane, and nine adjust in the vertical plane. Three main dipoles (two horizontal dipoles BNH2 and BNH1, and one vertical dipole STR1) and two vertical septum magnets (SEP2 and SEP3) also play a role in the position correction.

Based on the correction scheme mentioned above, the position displacements along the transfer line in both the horizontal and vertical planes are simulated. One thousand seeds are selected in the simulation. The results show that the maximum displacement after the correction is about 2.1 mm (Figure 5). At the MEB injection point the equivalent position displacements Δx_{eq} and Δy_{eq} are less than 0.02 mm, corresponding to an emittance growth of less than 0.1%, as shown in Figure 6. The maximum corrector strength required for this correction scheme is 0.7 mrad (Figure 7).

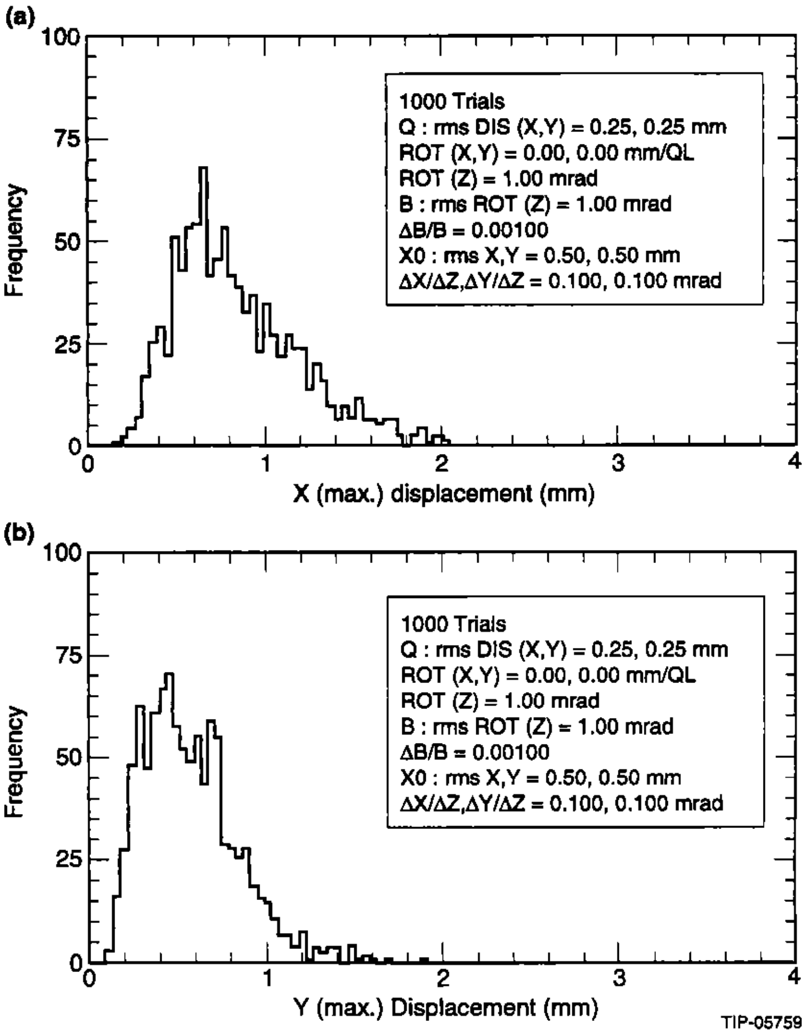

Figure 5. The Maximum Beam Position Displacements (LEB634E10).

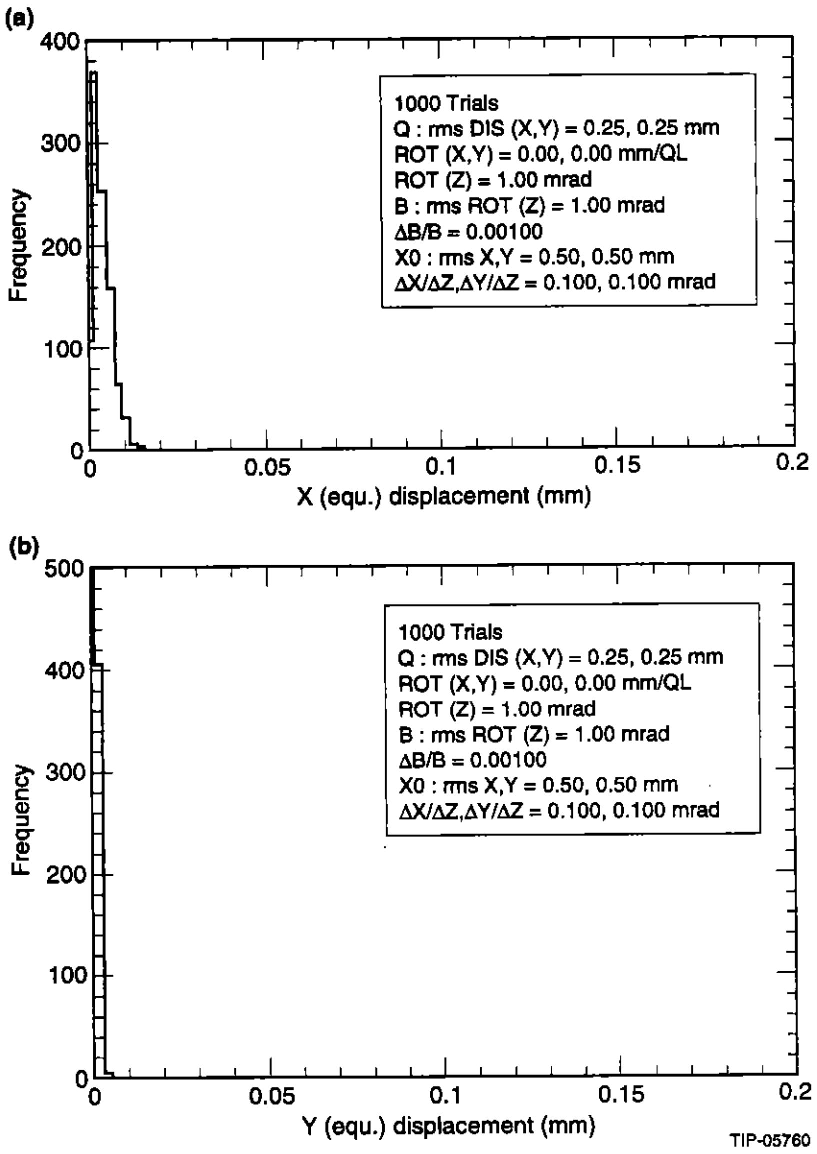

Figure 6. Equivalent Beam Position Displacements at the MEB Injection Point (LEB634E10).

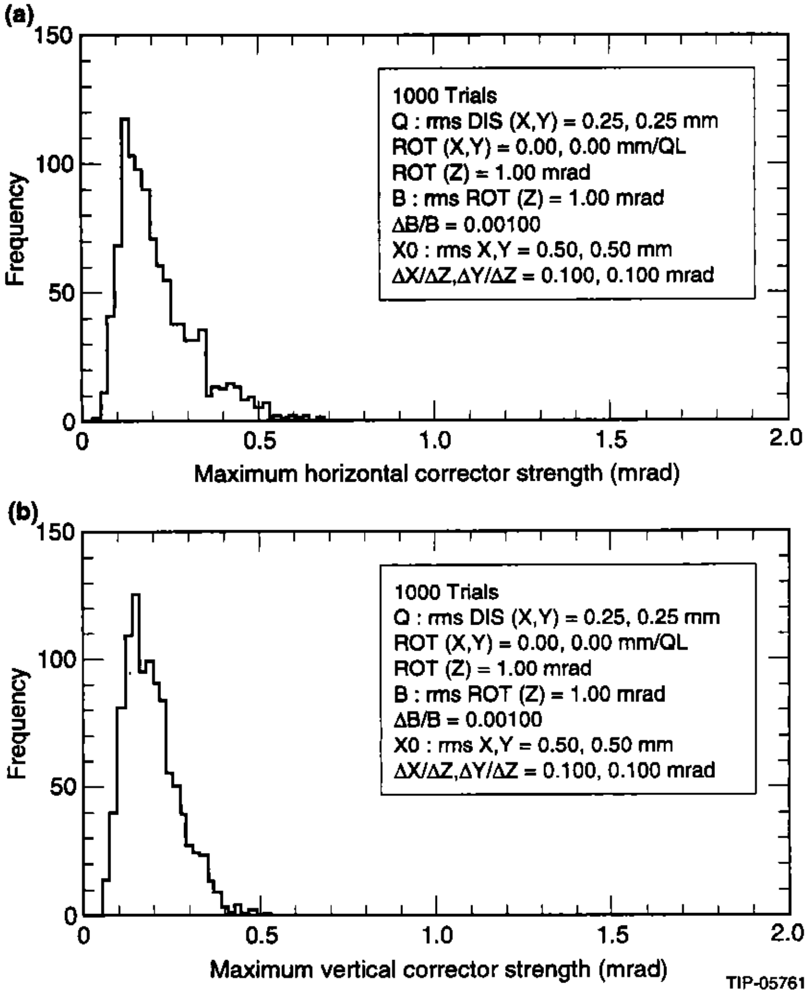

Figure 7. The Maximum Corrector Strength (LEB634E10).

4.0 CORRECTOR PARAMETERS AND MORE MONITORS

Based on the preceding position correction scheme, the required corrector parameters are determined and listed in Table 1. In order to prevent correctors from interfering in space with the LEB and MEB rings, the correctors located downstream of septum magnet SEP2 and upstream of septum magnet SEP3 have a physical cross-section constraint of less than 340 mm × 340 mm.

In general, BPMs installed in the transfer line are not only for beam position correction. BPMs are also needed for the LEB–MEB transfer line commissioning as follows:

1. in order to monitor the position and angle of the incoming beam from the LEB, two dual-direction BPMs are to be installed downstream of septum magnet SEP2 and upstream of quadrupole QU1 respectively;
2. the same with the injection beam into the MEB, two dual-direction BPMs are to be arranged upstream and downstream of septum magnet SEP3; and
3. in order to measure the η_x function, one more horizontal BPM located upstream of quadrupole Q07 is needed.

Table 1. Corrector Parameters.

	Requirements	Design Values
Number	17	17
Gap height (mm)	52	55
Physical cross-section ($w \times h$, mm × mm)	340 × 340	325 × 400 (C-type) 326 × 326 (H-type)
Physical length (m)		0.35
Magnet length (m)	0.25	0.25
Good field region ($w \times h$, mm × mm)	48 × 48	50 × 50
Field strength (T)	0.12	0.136
Integrated field strength ($T \times$ m)	0.030	0.034
Field quality ($\Delta BL/BL$)	1×10^{-3}	1×10^{-3}
Maximum correction strength (mrad)	0.75	0.85

5.0 BEAM POSITION CORRECTION OF LEB ABSORBER LINE

In addition to the LEB–MEB transfer line, there is an LEB beam absorber (beam dump) line, as shown in Figures 1 and 2, which transports the proton beam from the LEB to the absorber during the LEB commissioning. The absorber line separates from the transfer line at the entrance of dual-dipole STR2. All the dipoles, quadrupoles, correctors and BPMs located upstream of STR2 are shared by both lines. And all the magnets located downstream of quadrupole QU2 in the transfer line are turned off while the absorber line is in operation.

Based on the position correction scheme of the transfer line, the correction scheme of the absorber line is studied. Since emittance growth control is meaningless to the absorber line, only one constraint of limited magnet aperture is considered. The correction scheme of the absorber line is shown in Figure 8. Here the main dual-dipole DMP serves as a corrector. And two additional BPMs are arranged along the line, one horizontal BPM located upstream of quadrupole QDMP and one dual-direction BPM located upstream of the absorber. The statistical simulation results show that the maximum displacement along the line is 2.1 mm after the correction, and the maximum corrector strength required is 0.7 mrad, consistent with the values for the transfer line.

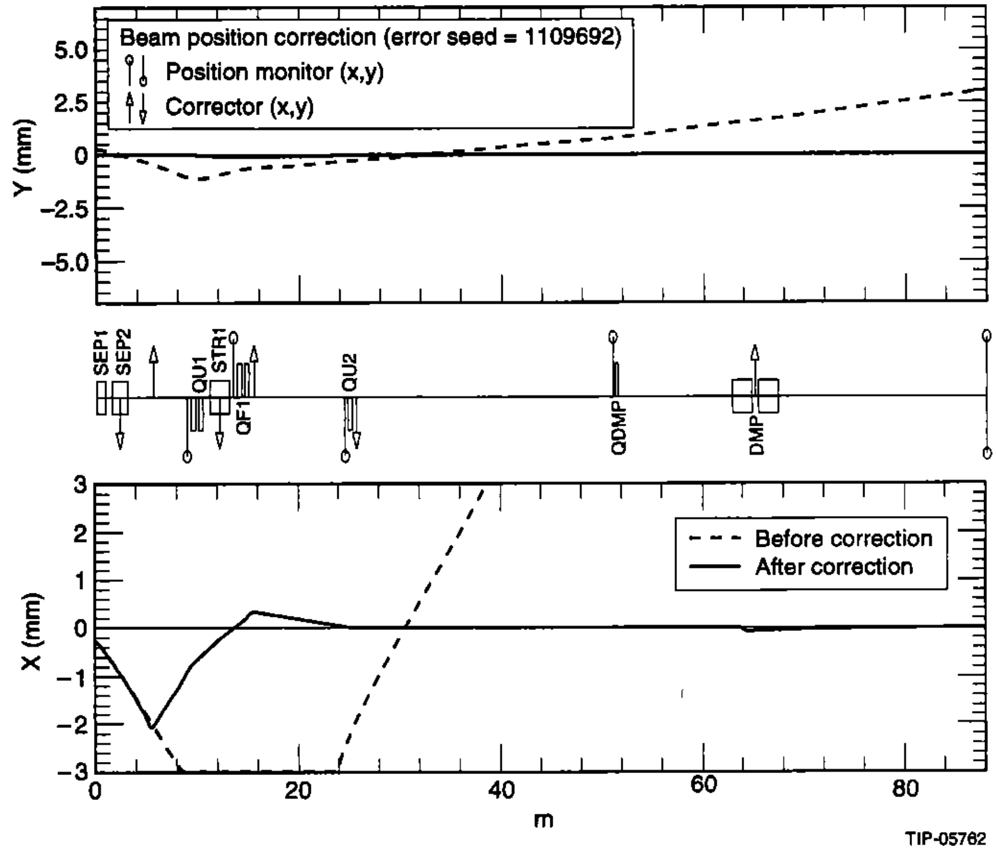

Figure 8. Beam Position Correction Scheme of the LEB Absorber Line (LEB919E03).

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