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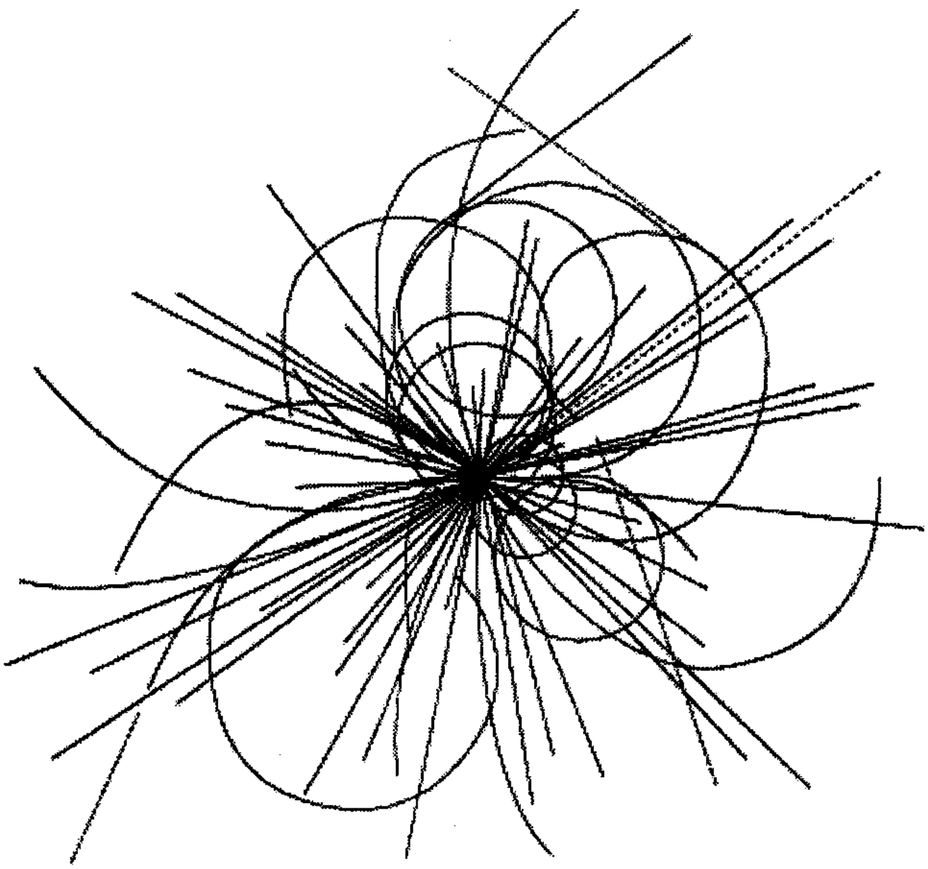

Superconducting Super Collider Laboratory

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Stability Requirements for Magnets in the LEB–MEB Transfer Line

N. Mao and R. Gerig

Abstract

The LEB–MEB transfer line at the Superconducting Super Collider Laboratory has 10 dipoles and 24 quadrupoles. A statistical method is used to study the stability requirements for these magnets.

1.0 INTRODUCTION

The LEB–MEB 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 and 24 quadrupoles. The field and gradient instabilities of dipoles and quadrupoles will cause beam injection position and amplitude function (β and α) mismatches at the MEB injection point, and therefore will cause transverse phase-space dilution. In order to study the effect of the instability on the emittance dilution, a statistical method and the corresponding code EAC[2,3] are used. According to the analyses, the requirements for the stabilities of the magnets are discussed.

2.0 STABILITY REQUIREMENTS FOR QUADRUPOLE GRADIENTS

The major effect of the quadrupole gradient instability is injection amplitude function (β and α) mismatch at the MEB injection point. The related transverse phase-space dilution factor ΔF is

$$\Delta F = 1/2*(\Delta\beta/\beta)_{eq}^{2}/[1 + (\Delta\beta/\beta)_{eq}],$$

where

$$(\Delta\beta/\beta)_{eq} \equiv (D-1) + (D^{2}-1)^{1/2}$$

$$D \equiv 1/2*(\beta_1\gamma_2 + \beta_2\gamma_1 - 2\alpha_1\alpha_2),$$

and subscripts 1 and 2 denote the quantities with and without gradient errors, respectively.

The layout (elevation view) of the LEB–MEB transfer line is shown in Figure 1. Among the 24 quadrupoles of the transfer line, five pairs (QU1, QF1, QFM1, QFM2, and QFM3) are powered in series. The instabilities of the two quadrupoles in each pair are coherent. In the statistical analyses of gradient instability, the error for each quadrupole or each pair of quadrupoles is chosen randomly. One thousand seeds are selected in the statistical calculation for a given rms gradient error.

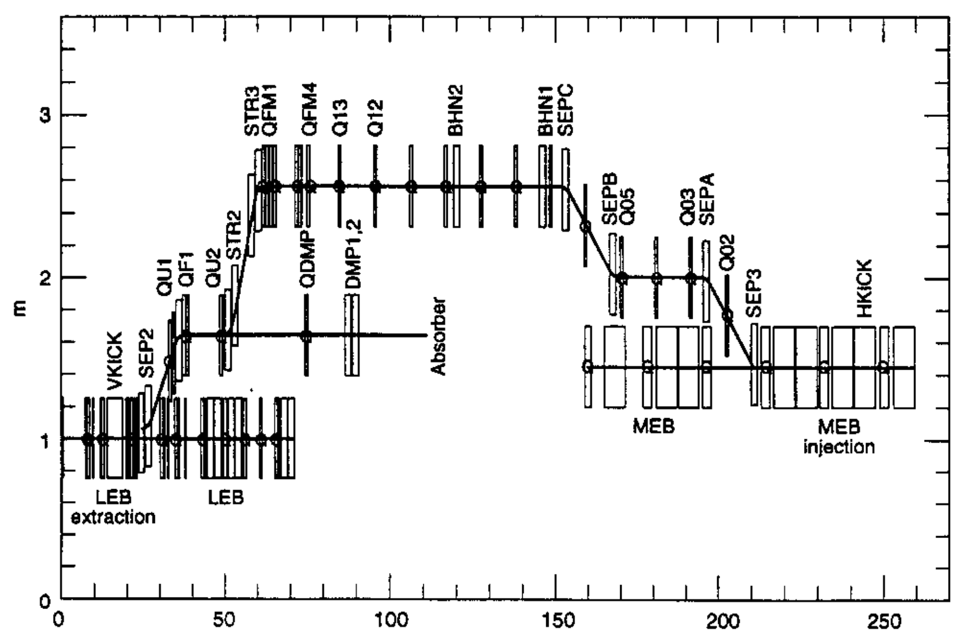

Figure 1. Layout of the LEB–MEB Transfer Line (elevation view, LEB630 and LEB917).

Figure 2 shows the histograms of the β-function mismatches, $(\Delta\beta_x/\beta_x)_{eq}$ and $(\Delta\beta_y/\beta_y)_{eq}$, for an rms gradient error of 1×10^{-3}. The corresponding phase-space dilution factors ΔF_x and ΔF_y are shown in Figure 3. Table 1 lists the dilution factors for $\Delta G/G = 1 \times 10^{-3}$ and 2×10^{-3}, where all values are rms. The analysis results show that the gradient instability of 1×10^{-3} is acceptable, as the phase-space dilution factors $\Delta F_x = \Delta F_y = 0.08\%$ are well under control.

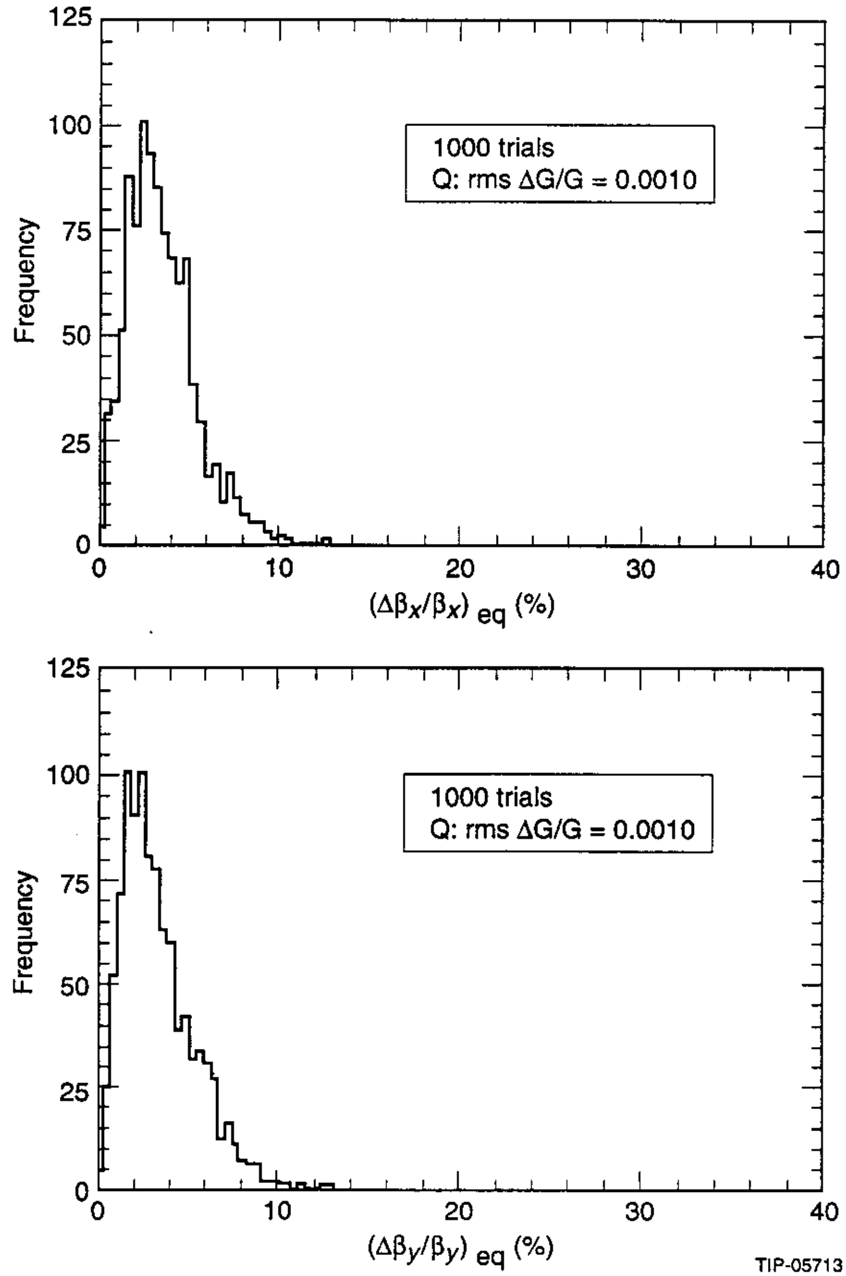

Figure 2. β Mismatches Caused by the Quadrupole Gradient rms Error of 1×10^{-3}.

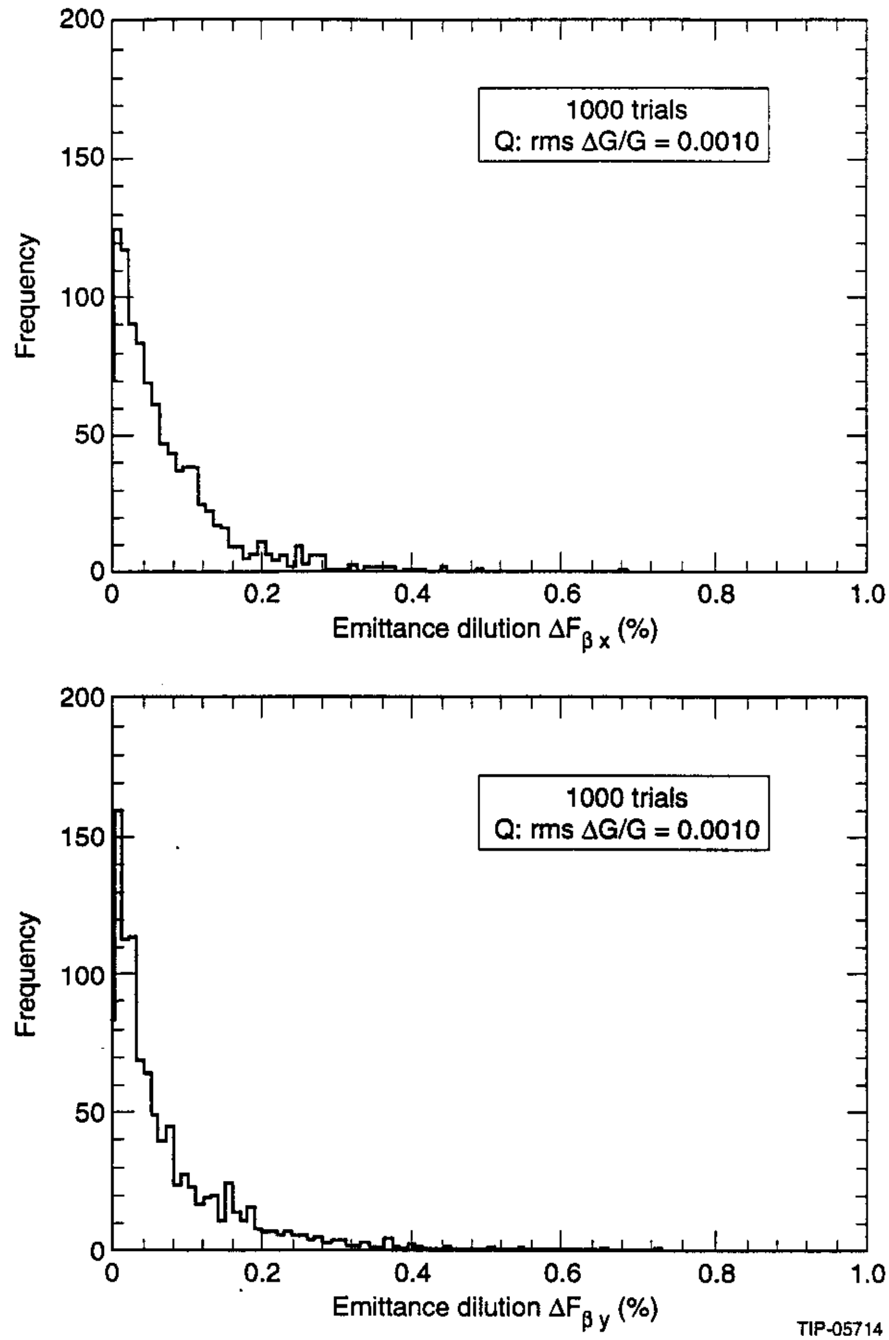

Figure 3. Emittance Dilutions Related to the Quadrupole Gradient rms Error of 1×10^{-3}.

Table 1. Quadrupole Gradient Instability and Phase-Space Dilution.

$\Delta G/G$	$(\Delta\beta x/\beta x)_{eq}$ (%)	$(\Delta\beta y/\beta y)_{eq}$ (%)	ΔF_x (%)	ΔF_y (%)	RUN
1×10^{-3}	4.1	4.1	0.08	0.08	LEB631EQ01
2×10^{-3}	8.3	8.0	0.31	0.30	LEB631EQ02

3.0 STABILITY REQUIREMENTS FOR DIPOLE FIELDS

The instability of dipole field causes beam position error and, therefore, phase-space dilution. For instance, in the horizontal plane:

$$\Delta F_x = 1/2*(\Delta X_{eq}/\sigma_x)^2,$$

where

$$\Delta X_{eq} \equiv [\Delta X^2 + (\beta\Delta X' + \alpha\Delta X)^2]^{1/2}.$$

There are ten dipoles in the transfer line; two pairs (STR2 and STR3) use multiple power supplies. A statistical analysis of the instability has been made. If the maximum value of field instability is $\Delta B/B$, an rms value $(\Delta B/B)_{rms} = (\Delta B/B)/2.58$ is used in the simulation. This means that 99% of events in the simulation may happen in practice. The number of seeds selected in the simulation is 1000.

Histograms of the equivalent beam position errors ΔX_{eq} and ΔY_{eq} at the MEB injection point, caused by the dipole field error $\Delta B/B = 1 \times 10^{-4}$, are shown in Figure 4. Histograms of the maximum beam position displacements along the beam line are shown in Figure 5. Table 2 lists the equivalent position errors ΔX_{eq} and Δ_{eq}, the phase-space dilution factors ΔF_x and ΔF_y, and the maximum displacements ΔX_{max} and Δ_{max} along the beam line for $\Delta B/B = (1–3) \times 10^{-4}$. Since eight dipoles are bending in the vertical direction (y), the errors in y-direction are larger than in x-direction.

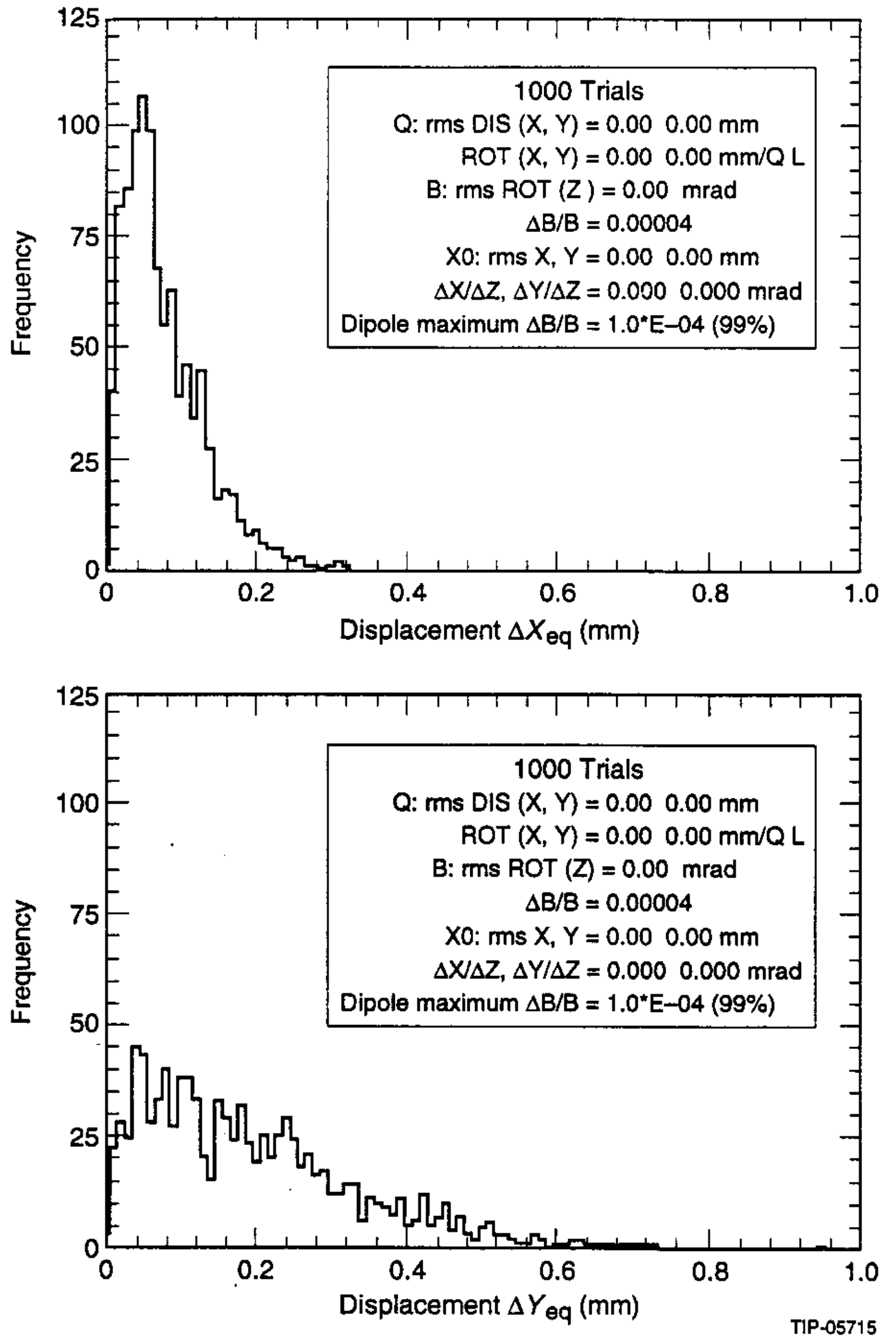

Figure 4. Equivalent Beam Position Errors Caused by the Dipole Field rms Error of 1×10^{-4}.

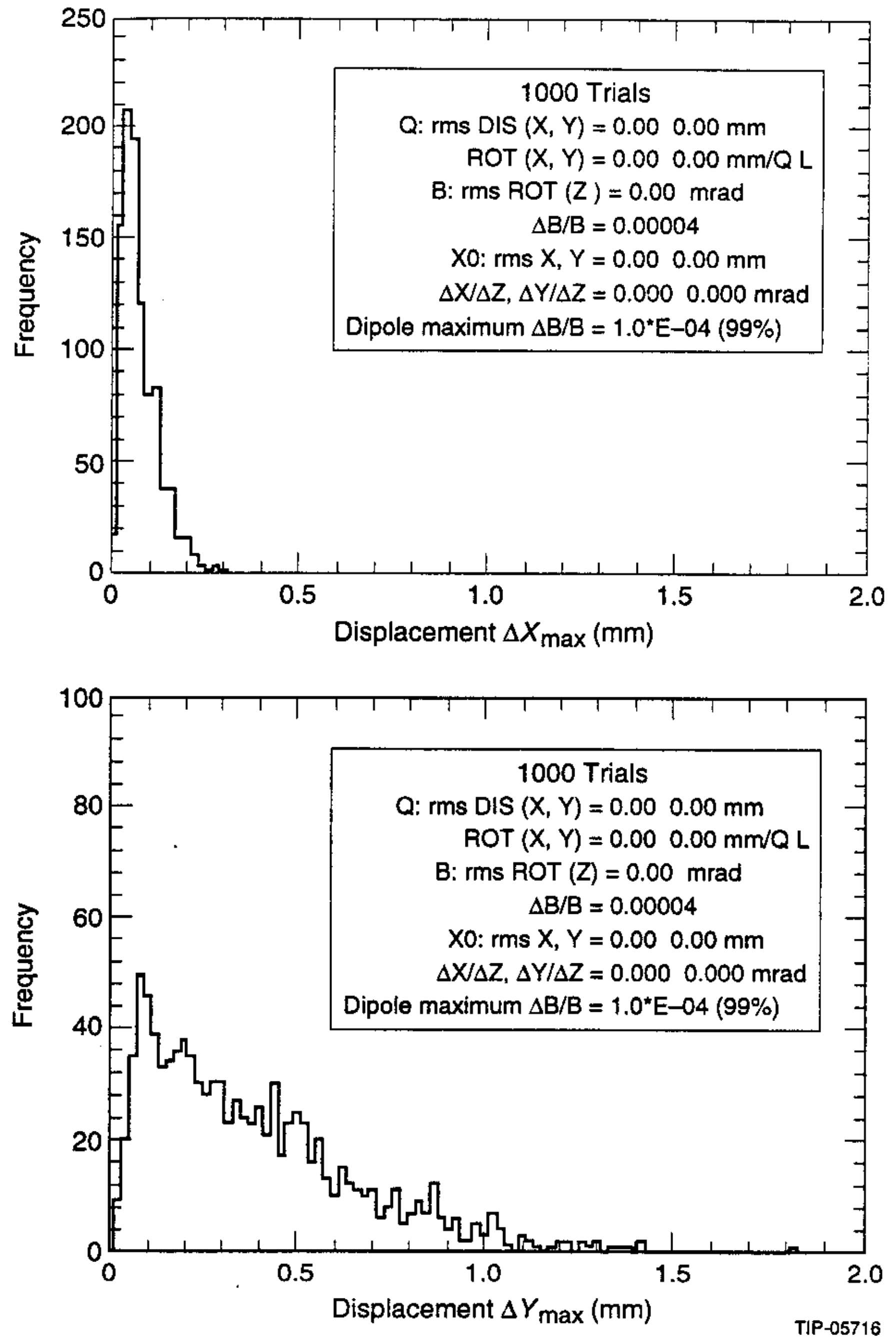

Figure 5. Maximum Beam Position Displacements Caused by the Dipole Field rms Error of 1×10^{-4}.

Table 2. Dipole Field Instability and Phase-Space Dilution.

$\Delta B/B$	ΔX_{eq} (mm)	ΔY_{eq} (mm)	ΔF_x	ΔF_y	ΔX_{max} (mm)	ΔY_{max} (mm)	RUN
1×10^{-4}	0.25	0.63	0.013	0.294	0.23	1.26	LEB633ED51
2×10^{-4}	0.50	1.27	0.052	1.193	0.46	2.50	LEB633ED52
3×10^{-4}	0.76	1.88	0.120	2.614	0.70	3.77	LEB633ED53

Except for these ten dipoles, the field instabilities of all other bending magnets, including the LEB extraction kicker (VKICK, 1×10^{-2}), bump magnets (BMP1, 2, and 3, 1×10^{-3}), septum magnets (SEP1, 2×10^{-3}; SEP2, 1×10^{-3}), MEB injection septum magnet (SEP3) and injection kicker (HKICK, 1×10^{-2}), also cause beam position errors and phase-space dilutions, as listed in Table 3. In the table, $\Delta B/B$ of the ten dipoles and septum SEP3 is taken as 1×10^{-4}. The total phase-space dilution factor equals the summation of all individual values:

$$\Delta F = \Sigma \Delta F_i \ ,$$

and correspondingly, the total position errors should be calculated as

$$\Delta X = [\Sigma \Delta X_i^2]^{1/2} \ .$$

Table 3. Instability of All Bending Magnets and Phase-Space Dilution (Dipoles and SEP3 $\Delta B/B = 1 \times 10^{-4}$).

Magnet	$\Delta B/B$	ΔX_{eq} (mm)	ΔY_{eq} (mm)	ΔF_x	ΔF_y	ΔX_{max} (mm)	ΔY_{max} (mm)	RUN
BMP1	1×10^{-3}		0.04		0.001		0.10	LEB633ED02
VKICK	1×10^{-2}		0.26		0.050		0.63	LEB633ED54
BMP2	1×10^{-3}		0.03		0.001		0.05	LEB633ED03
BMP3	1×10^{-3}							
SEP1	2×10^{-3}		0.11		0.009		0.23	LEB633ED55
SEP2	1×10^{-3}		0.74		0.405		1.40	LEB633ED56
Dipoles	1×10^{-4}	0.25	0.63	0.013	0.294	0.23	1.26	LEB633ED51
SEP3	1×10^{-4}		0.06		0.003		0.10	LEB633ED18
HKICK	1×10^{-2}	0.39		0.032		0.03		LEB633ED57
Total		0.46	1.02	0.045	0.763	0.23	2.01	

The last line of this table gives all the total errors, including ΔF_x, ΔF_y, ΔX_{eq}, ΔY_{eq}, ΔX_{max}, and ΔY_{max}.

When $\Delta B/B$ of the ten dipoles and the septum SEP3 is taken as 2×10^{-4} or 3×10^{-4}, the total position errors and the phase-space dilution factors increase correspondingly, as shown in Table 4.

Table 4. **Instability of All Bending Magnets and Phase-Space Dilution (for Different $\Delta B/B$ and SEP3).**

$\Delta B/B$	ΔX_{eq} (mm)	ΔY_{eq} (mm)	ΔF_x	ΔF_y	ΔX_{max} (mm)	ΔY_{max} (mm)
1×10^{-4}	0.46	1.02	0.045	0.763	0.23	2.01
2×10^{-4}	0.63	1.50	0.084	1.669	0.46	2.95
3×10^{-4}	0.85	2.05	0.152	3.102	0.70	4.00

The current MEB damping system can damp 2 mm injection position errors; therefore, a stability of $(1\text{–}2) \times 10^{-4}$ is really needed. In order to leave some margin (say, for LEB closed-orbit instability), 1×10^{-4} is required (3B Spec[4]). On the other hand, the magnet apertures in the transfer line have only 2 mm space for the beam position errors caused by instability. For keeping ΔX_{max} and ΔY_{max} less than 2 mm, 1×10^{-4} is also required.

It must be pointed out that this requirement is only for collider operation mode in a short time period of 1 h, mainly for the ripple. As for the long-term variation, it could be tuned up over various time periods.

The stability requirement analyzed above is for the magnet field. As for the power supplies, the stability requirement can be relaxed, if the following points are considered:

1. Locking the LEB extraction process at a fixed phase of the ripple wave—for instance, near the top of the ripple wave;
2. The field variation in the magnet should be less than the power supply instability (ripple, 720 Hz), because of the inductance of the solid magnets used.

REFERENCES

1. Naifeng Mao *et al.*, "Beam Optics of LEB–MEB Transfer Line for Superconducting Super Collider," *Proceedings of the 1993 Particle Accelerator Conference*, Washington, D.C., p. 333.

2. Fuhua Wang and Naifeng Mao, "Beam Line Error Analysis, Position Correction and Graphic Processing," SSCL-654, Superconducting Super Collider Laboratory, Dallas, 1993, or *AIP Conference Proceedings* **297**, Computational Accelerator Physics, Pleasanton, CA, 1993, p. 135.

3. Karl Brown *et al.*, "TRANSPORT, a Computer Program for Designing Charged Particle Transport Systems," SLAC-91, Rev. 3, 1993.

4. "Element Specification (Level 3B) for the Low Energy Booster to Medium Energy Booster (LEB-MEB) Beam Transfer Line of the Superconducting Super Collider," No. E10-000030, WBS 222, Rev. D, Superconducting Super Collider Laboratory, 1994.