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Injection System of the SSC Medium Energy Booster

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Abstract

The Medium Energy Booster (MEB) is the third of the SSCL accelerators and the largest of the resistive magnet synchrotrons. It accelerates protons from an injection momentum of 12 GeV/c to a top momentum of 200 GeV/c. A beam injection system has been designed to inject the beam transferred from the Low Energy Booster (LEB) onto the MEB closed orbit in the MEB injection insertion region. The beam is injected via a vertical bending Lambertson septum magnet and a horizontal kicker with appropriate matching and very little beam loss and emittance dilution.

The beam optics of the injection system is described in this paper. The required parameters of the Lambertson septum magnet and the injection kicker are given.

1.0 INTRODUCTION

The MEB ring layout and the detail of the MEB injection insertion are shown in Figure 1.[1] The injection insertion adopts the standard FODO quadrupole spacing and uses missing dipoles to provide spaces for the beam transfer line,[2] septum magnet and kicker. The injection philosophy is as follows. The septum magnet (SEP3, Figures 2 and 3), located right upstream of the focusing quadrupole Q152, bends the beam up by 2.173° onto the MEB closed orbit plane. The horizontal kicker (HKICK), located right upstream of the focusing quadrupole Q154, completes the injection process, placing the beam onto the proper MEB horizontal closed orbit. This scheme takes advantage of the defocusing quadrupole Q153 present between the septum magnet and the horizontal kicker. The defocusing quadrupole bends the injection beam outward in the horizontal plane, thereby lessening the necessary strength of the injection kicker.

The lattice functions of the injection insertion are shown in Figure 4.[1] The functions at the exits of the septum magnet and the injection kicker are also listed in Table 1, lines 38 and 52, respectively. The injection system has been designed to inject the beam in both the collider fill mode and the test beam mode with the normalized transverse emittances (rms) of 0.6 π*mm*mrad and 4.0 π*mm*mrad, respectively.

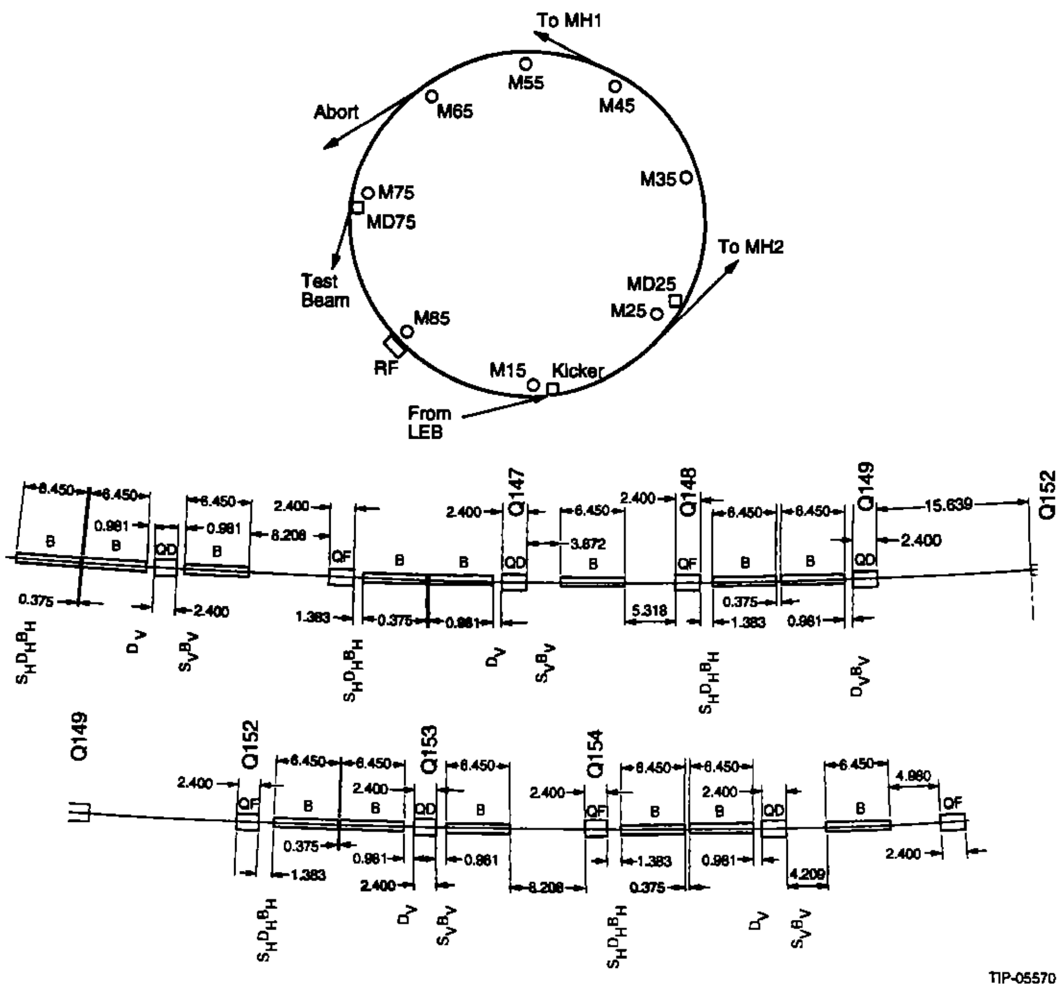

Figure 1. MEB Ring Layout and Injection Insertion.

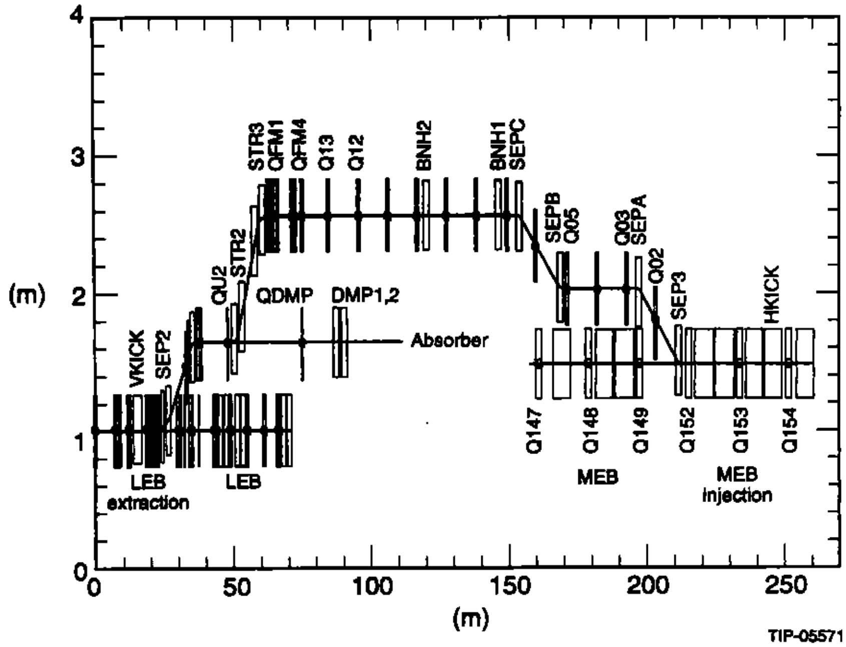

Figure 2. LEB–MEB Transfer Line and Absorber Line (Elevation View, LEB630 and LEB917).

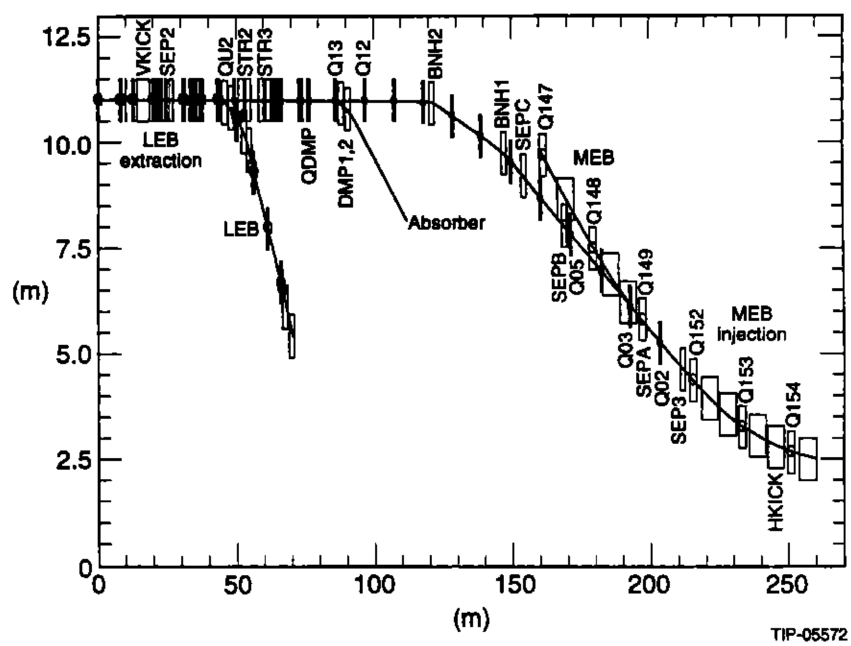

Figure 3. LEB–MEB Transfer Line and Absorber Line (Plan View, LEB630 and LEB917).

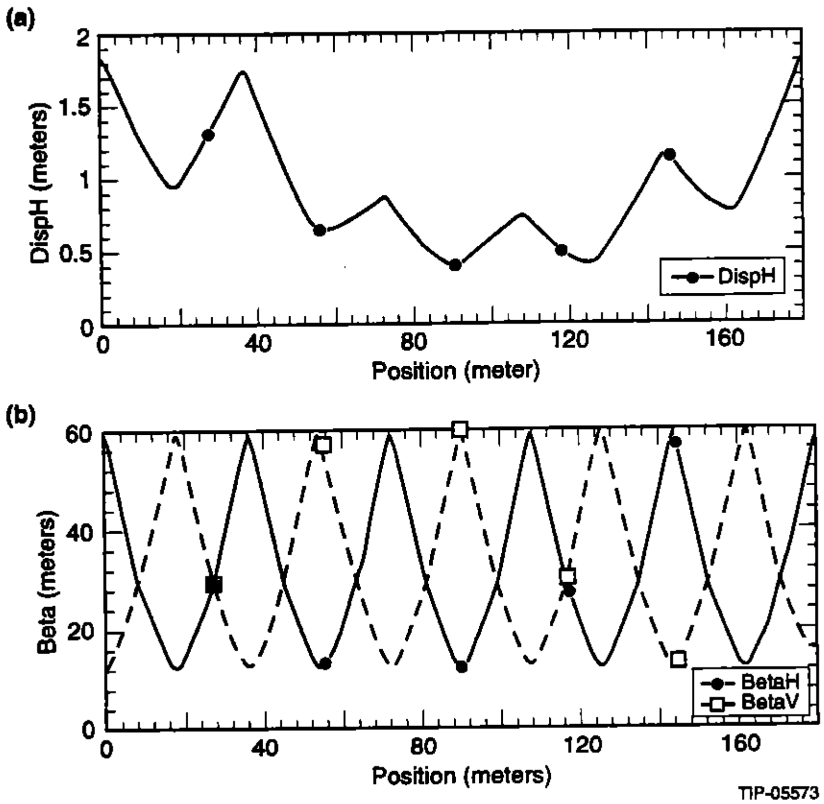

Figure 4. Lattice and Orbit Functions for Injection Insertion.

Table 1. Lattice Functions for the MEB Injection Insertion.

SYNCH RUN MEB   90 deg MEB lattices   SYNCH VERSION VAX.8905
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POS		S	QX	BX	AX	X	DX	QY	BY	AY	Y	DY
0		0.0000	0.000000	59.8268	0.000000	1.846800	0.000000	0.000000	11.9111	0.000000	0.000000	0.00000
5	B	15.8580	0.089819	14.0485	0.694846	0.986929	-0.036702	0.112219	52.5069	-2.137776	0.000000	0.00000
10	B	26.6708	0.197473	27.4022	-1.375607	1.279710	0.054087	0.150734	29.3312	1.454812	0.000000	0.00000
15	QF	37.2788	0.237227	57.0951	2.242003	1.690605	-0.081201	0.252372	12.6105	-0.584100	0.000000	0.00000
20	OOD	52.9183	0.335468	12.7860	0.591278	0.685626	-0.046431	0.351626	56.8462	-2.242883	0.000000	0.00000
25	DXD	70.9577	0.464730	57.0935	-2.241911	0.856447	0.021973	0.457415	12.6084	0.583586	0.000000	0.00000
30	O	81.5657	0.504483	27.4020	1.375603	0.523524	-0.027412	0.559048	29.3349	-1.454346	0.000000	0.00000
35	OOD	92.3785	0.612137	14.0484	-0.694847	0.426085	0.020797	0.597564	52.4969	2.137999	0.000000	0.00000
36	SB	98.8285	0.665449	27.4031	-1.375647	0.560228	0.020797	0.623844	29.3316	1.453517	0.000000	0.00000
37	O	99.2035	0.667586	28.4497	-1.415229	0.568027	0.020797	0.625917	28.2564	1.413721	0.000000	0.00000
38	SB	105.6535	0.694641	51.0973	-2.096029	0.702171	0.020797	0.677654	14.4343	0.729238	0.000000	0.00000
39	OOF	107.0365	0.698716	57.0968	-2.242005	0.730933	0.020797	0.693991	12.6202	0.582472	0.000000	0.00000
40	QF	108.2365	0.701959	59.8299	0.000041	0.738657	-0.007975	0.709701	11.9334	-0.001248	0.000000	0.00000
41	QF	109.4365	0.705201	57.0966	2.242080	0.711942	-0.036376	0.725407	12.6264	-0.585206	0.000000	0.00000
42	OOF	110.8195	0.709277	51.0969	2.096095	0.661635	-0.036376	0.741732	14.4484	-0.732250	0.000000	0.00000
43	B	117.2695	0.736330	28.4496	1.415289	0.483088	-0.018991	0.793390	28.3119	-1.416805	0.000000	0.00000
44	O	117.6445	0.738467	27.4030	1.375705	0.475967	-0.018991	0.795459	29.3895	-1.456638	0.000000	0.00000
45	B	124.0945	0.791776	14.0482	0.694899	0.409548	-0.001605	0.821690	52.5875	-2.139406	0.000000	0.00000
46	OOD	125.0760	0.803441	12.7859	0.591304	0.407972	-0.001605	0.824546	56.8889	-2.243489	0.000000	0.00000
47	QD	126.2760	0.818949	12.0872	0.000055	0.415664	0.014475	0.827800	59.6220	0.001762	0.000000	0.00000
48	QD	127.4760	0.834458	12.7857	-0.591183	0.442985	0.031239	0.831054	56.8807	2.246686	0.000000	0.00000
49	OOD	128.4574	0.846123	14.0477	-0.694769	0.473644	0.031239	0.833910	52.5732	2.142341	0.000000	0.00000
50	B	134.9074	0.899435	27.4004	-1.375517	0.731189	0.048624	0.860163	29.3485	1.457844	0.000000	0.00000
51	O	135.2824	0.901573	28.4469	-1.415098	0.749423	0.048624	0.862235	28.2701	1.417911	0.000000	0.00000
52	SB	141.7324	0.928630	51.0927	-2.095880	1.063048	0.048624	0.914005	14.4093	0.731054	0.000000	0.00000
53	OOF	143.1154	0.932706	57.0918	-2.241853	1.130295	0.048624	0.930376	12.5909	0.583779	0.000000	0.00000
54	QF	144.3154	0.935949	59.8248	-0.000006	1.161841	0.003747	0.946126	11.9000	0.000906	0.000000	0.00000
55	QF	145.5154	0.939191	57.0918	2.241842	1.139219	-0.041304	0.961879	12.5864	-0.581794	0.000000	0.00000
60	OOD	161.1548	1.037435	12.7862	0.591220	0.758176	-0.006534	1.061342	56.7476	-2.240424	0.000000	0.00000
65	DXB	179.1942	1.166690	57.0972	-2.242040	1.804189	0.071550	1.167175	12.6214	0.582155	0.000000	0.00000
66	QF	180.3942	1.169933	59.8304	0.000024	1.847322	0.000059	1.182882	11.9354	-0.001596	0.000000	0.00000

2.0 BEAM OPTICS OF INJECTION SYSTEM

The layout of the injection system is shown in Figure 5. The injection kicker (HKICK) is one cell downstream of the septum magnet (SEP3). The central trajectory separation between the injection beam and the circulating beam at the exit of the septum magnet in the horizontal plane is given by

$$\Delta x = K\sqrt{\beta_1\beta_2}\sin(\phi_2 - \phi_1) \tag{1}$$

where K is the kicker strength, β_1 and β_2 are the β functions and ϕ_2 and ϕ_1 are the betatron phases at septum magnet exit and the kicker, respectively. Here the kicker is assumed to be a thin one. If the kicker has a length of L, the separation Δx is given by

$$\Delta x = \frac{K}{L}\sqrt{\beta_1}\int_0^L \sqrt{\beta_2(l)}\sin(\phi_2(l) - \phi_1)\,dl\ . \tag{2}$$

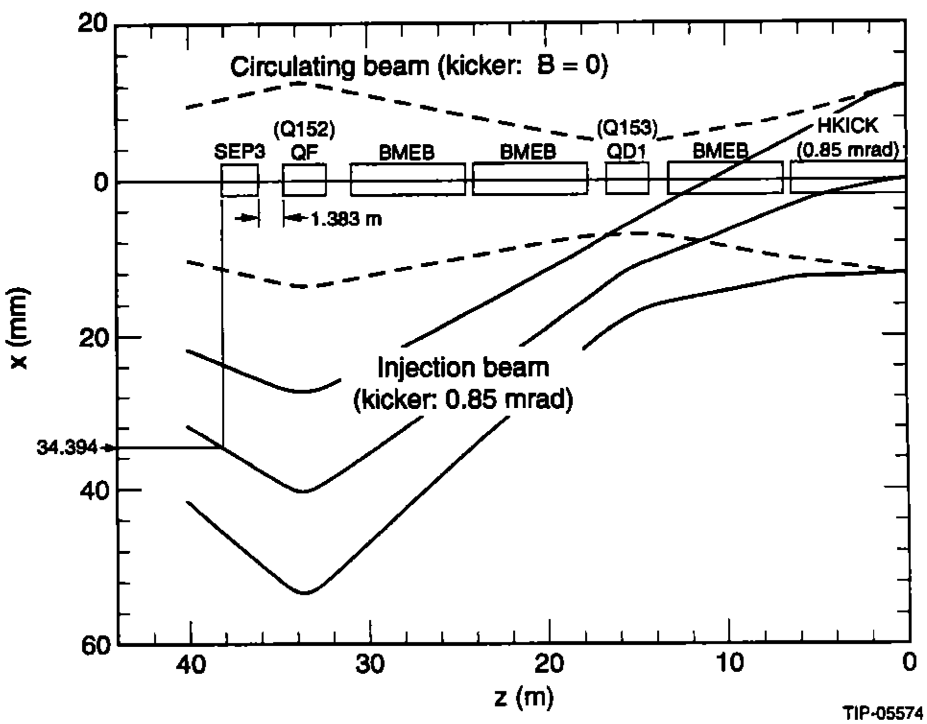

Figure 5. Layout of MEB Injection System.

The requirement for the separation between the two beam centroids at the septum magnet is related to the sizes of two beams, the beam centroid displacements caused by the magnet errors, and the thickness of the septum magnet. The parameters used in the injection system design are as follows:

The normalized beam transverse emittance (3σ test beam) = 9*4 π*mm*mrad.

The β and η functions at the exit of the kicker,

β_x = 51.0927 m
β_y = 14.4093 m
α_x = – 2.09588
α_y = 0.731054
η_x = – 1.063048 m
η_y = 0 m
η_x' = – 0.048624
η_y' = 0.

The beam centroid displacement caused by the magnet errors = 3 mm.

The thickness of the septum = 2 mm.

Using these parameters, both analytical and numerical calculations show that a kicker strength of 0.85 mrad is adequate. It corresponds to a separation of 34.394 mm between the two beam centroids at the entrance of the septum magnet. This amount of separation is large enough to provide a 2.0 mm space for the septum. The numerical calculation is carried out with code TRANSPORT.[3] The layout of the injection system is shown in Figure 5; the beam parameters are shown in Figure 6 and explained as follows.

(1) Beam sizes (3σ, 4π*mm*mrad test beam, $\delta p/p$ = 0.1%)

Circulating beam (Run LEB018A):

11.039 mm*7.074 mm, half size, at the entrance of the septum magnet,

12.013 mm*6.374 mm, half size, at the exit.

Injection beam (Run LEB018C and LEB630E):

11.028 mm*7.074 mm, half size, at the entrance of the septum magnet,

12.011 mm*6.374 mm, half size, at the exit.

(2) Separations between the two centroids of circulating beam and injection beam (Run LEB018C and LEB630E)

Horizontal separations:

34.394 mm, at the entrance of the septum magnet,

37.219 mm, at the exit.

Vertical separations:

37.928 mm, at the entrance of the septum magnet,

0.000 mm, at the exit.

The geometry of the Lambertson septum magnet is so arranged that the mid-plane of the magnet gap is parallel with the central trajectory plane of the injection beam. The minimum edge-to-edge separation of the two beams in the horizontal direction (from the right edge of the circulating beam to the left edge of the injection beam) is 11.344 mm, as shown in Figure 6. If the beam centroid displacement caused by magnet errors is 3.0 mm, the distance from the right edge of the circulating beam to the vertex of the field-free region has to be at least 6.315 mm, as shown in Figure 7. In this case, the space available for septum is 2.029 mm (Figure 6), it meets the requirement.

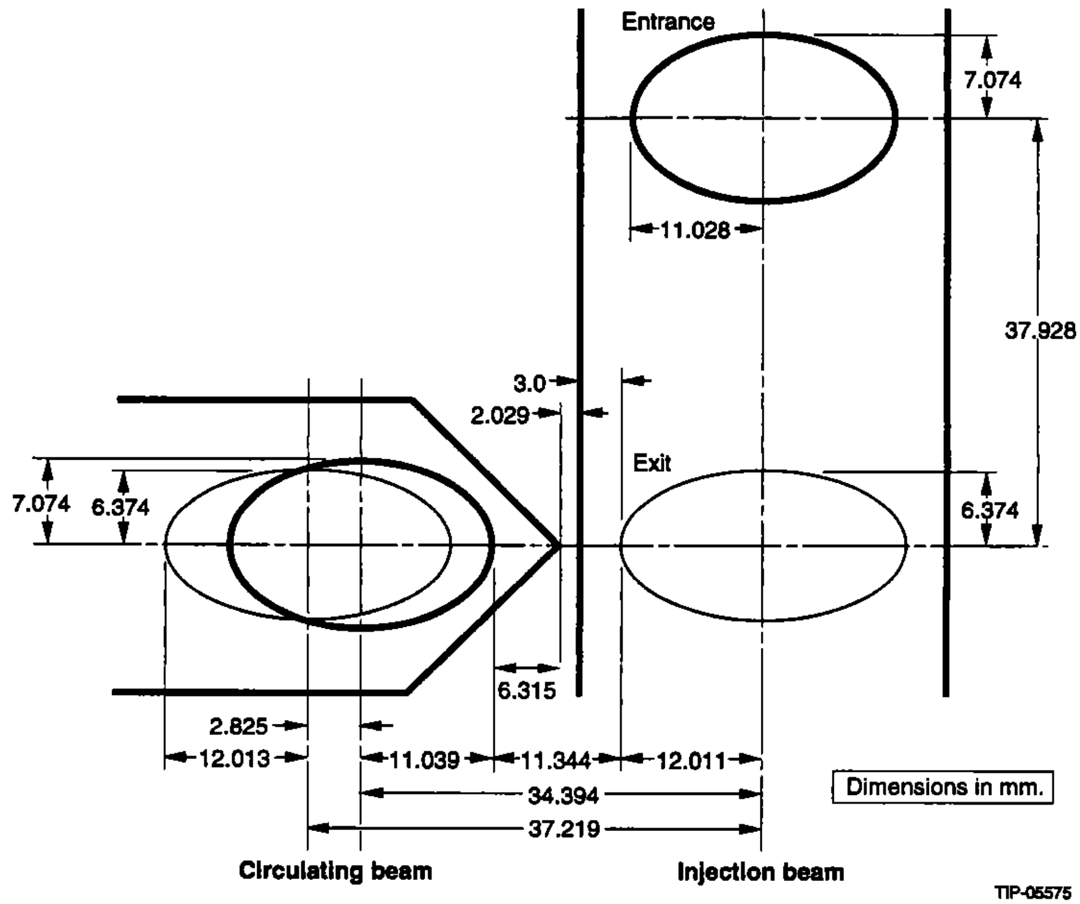

Figure 6. Beam Parameters in the Septum Magnet.

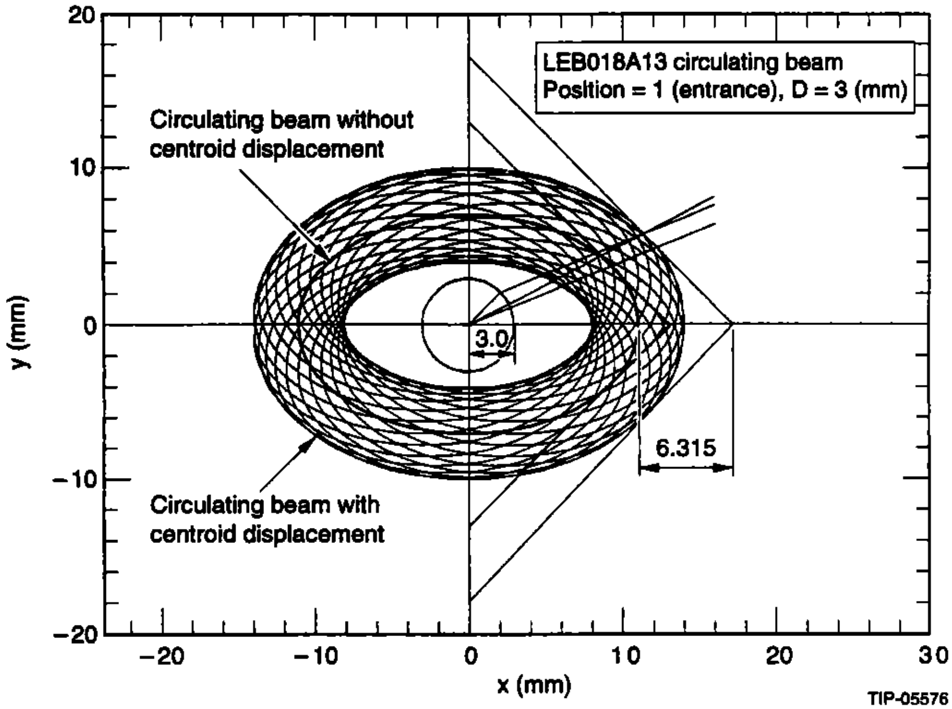

Figure 7. Circulating Beam with or without Centroid Displacement Caused by Magnet Errors.

3.0 PARAMETERS OF SEPTUM MAGNET AND INJECTION KICKER

Based on the beam optics design of the MEB injection system, the main parameters of the injection Lambertson septum magnet are determined as follows:[4]

Number	1
Field aperture (w*h)	>60 mm * ± 15 mm
Field-free aperture (w*h)	50.8 mm * 70 mm
Leakage field in field-free region	<0.0008 T
(max, at the center	<0.02 T/m
of circulating beam)	<0.2 T/m^2
Magnet length	2.0 m
Good field region (w*h)	60 mm * ± 15 mm
Field (max)	0.78 T
Field quality (ΔBL/BL)	1*10^{-4}
TOD of power supply	1*10^{-4}

Here, w and h are with respect to the magnet gap, h is measured in the gap height direction. The conceptual design of the Lambertson septum magnet is shown in Figure 8.[5]

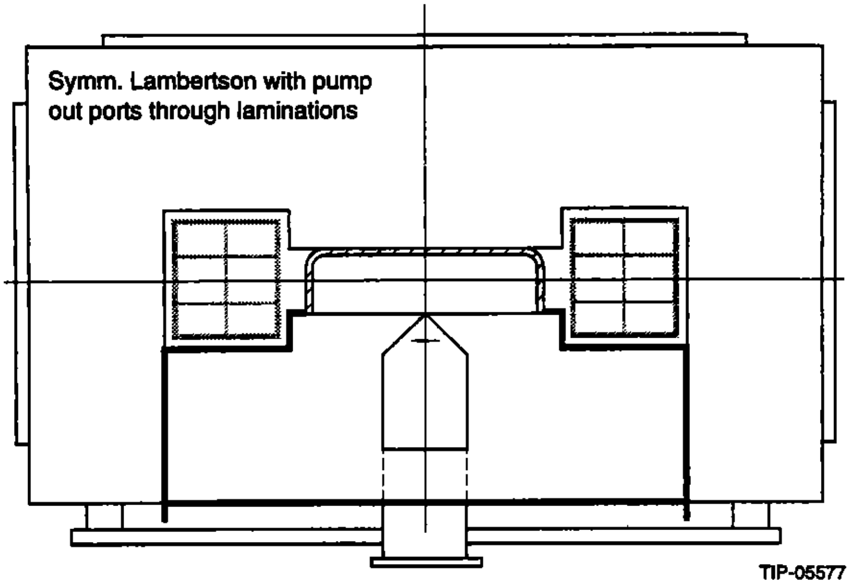

Figure 8. Conceptual Design of the Lambertson Septum Magnet.

The requirements for the injection kickers are as follows:

Number of magnets	≥ 4
Slot length	6.45 m
Aperture (H*V)	100 mm*50 mm
Strength (bending angle)	0.90 mrad
BL	0.036 T*m
TOD of power supply	$1*10^{-2}$

A twelve magnets kicker system design has been reported,[6] where each magnet consists of ten cells.

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