BNL-105236-2014-TECH

Booster Technical Note No. 192;BNL-105236-2014-IR

IMPROVEMENT of the BOOSTER HEAVY ION INJECTION LINE

J. Xu

May 1991

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

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IMPROVEMENT of the BOOSTER HEAVY ION INJECTION LINE

BOOSTER TECHNICAL NOTE
NO. 192

J. XU

MAY 14, 1991

ALTERNATING GRADIENT SYNCHROTRON DEPARTMENT
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IMPROVEMENT OF THE BOOSTER HEAVY ION INJECTION LINE

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May 23, 1991

The layout and beam optics of the new design of the heavy ion injection line for the AGS booster have been described in reference 1 by R.C. Gupta et al. In their design, at the booster injection point there is vertical dispersion mismatch and MAD program was used. I have run the same lattice with both MAD and SYNCH programs. Dr. Milutinovic has run it with program PATRIS. The outputs from different programs are really different slightly. The output of MAD program is shown in Table 1, the input data and output of SYNCH are shown in Table 2 and Table 3 respectively. The Twiss parameters and dispersion functions at the booster injection point from different programs are shown in the following table, Table 4,

Table 4

	β_x	α_x	η_x	η'_x	μ_x	β_y	α_y	η_y	η'_y	μ_y
MAD	13.976	-0.208	2.82	0.286	1.545	3.568	0.304	0.391	0.119	0.973
SYNCH	13.976	-0.208	2.82	0.286	1.545	3.547	0.307	0.485	0.057	0.972
PATRIS[2]	12.550	-0.073	2.82	0.286	1.552	3.514	0.359	0.391	0.119	0.967

The dispersion functions from MAD coincide with those from PATRIS and the Twiss parameters from MAD coincide with those from SYNCH. The discrepancy is produced due to the tilt of bending magnets. From the above results, one can assume that, the output of MAD is reliable even though in its output there is a warning message.

The focusing parameters and the location of the quadrupoles have been tuned so that to get a better match at the booster injection point. In this process, MAD program was used. The output are shown in Table 5.

Next, the emittance dilution due to dispersion mismatch will be estimated. Suppose, the Twiss parameters in y–direction at the booster injection point are α, β, γ, η_y and η'_y, the dispersion function of the injection line at the injection point are $\eta_{y\ell}$, $\eta'_{y\ell}$ and momentum error is $\frac{\Delta p}{p}$, then the emittance dilution factor F is expressed as follows[3]

$$F = \left[1 + \sqrt{\frac{\epsilon_p}{\epsilon_o}}\right]^2 \tag{1}$$

where ϵ_o is the emittance of the injected beam and ϵ_p can be expressed as follows

$$\epsilon_p = \left(\frac{\Delta p}{p}\right)^2 \left[\gamma\left(\eta_{y\ell} - \eta_y\right)^2 + 2\alpha\left(\eta_{y\ell} - \eta_y\right)\left(\eta'_{y\ell} - \eta'_y\right) + \beta\left(\eta'_{y\ell} - \eta'_y\right)^2\right] \tag{2}$$

For the original injection line lattice, the emittance dilution factor due to vertical dispersion mismatch will be:

$$F = \left[1 + \frac{\Delta p}{p}\left(\frac{0.126}{\epsilon_o}\right)^{1/2}\right]^2 . \tag{3}$$

From reference 4 $\epsilon_o \approx 1$ mm·mrad, then

$$F = \left[1 + 0.35\frac{\Delta p}{p}\right]^2 \tag{4}$$

where $\frac{\Delta p}{p}$ is expressed in 10^{-3}. The emittance dilution factors F corresponding to various $\frac{\Delta p}{p}$ are shown in the following table,

F	1.83	1.38	1.14
$\frac{\Delta p}{p}\,(10^{-3})$	1	0.5	0.2

For the improved lattice, F due to η_y' mismatch can be expressed as follows

$$F = \left[1 + 5.7 \times 10^{-3}\frac{\Delta p}{p}\right]^2 . \tag{5}$$

F due to β_y, α_y small mismatch is 1.007. Both F's equal 1 approximately. The emittance dilution is negligibly small. One thing should be pointed out is that the maximum β_y in this lattice is approximately 100 meters, but the beam size remains well within the 4″ aperture of the quadrupoles. Another possibility to improve this line is to tune the upstream line focusing parameters or to tune the whole line from Tandem to booster injection point.

Acknowledgments

I am thankful to Dr. A.G. Ruggiero for valuable discussion and Dr. S. Tepikian and J. Milutinovic for their help in running SYNCH program.

References

1. R.C. Gupta, R. Damm, Y.Y. Lee and W.T. Weng, H^- and Heavy Ion Injection Lines for the Booster, Booster Technical Note No. 90, Sept. 1987.
2. J. Milutinovic, private communication, 1991.
3. J. Xu, J. Claus and A.G. Ruggiero, A Feedback Device to Damp the Coherent Oscillations from Injection Errors in RHIC, AD/RHIC Technical Note No 74, 1990.
4. Booster Design Manual, p. 4–16.

Table 1.

```
1"MAD" Version 7.2/VAX                  Copyright (C) 1988 by CERN.

 Date and time of this run:     25-APR-9     16:16:12

               MQFC3:QUAD,L=0.25,K1=.554569
               MDR:DRIFT,L=.30
               HIKICK:SBEND,L=1.6,ANGLE=-.180056

               HILA:DRIFT,L=2.0
               HILB:DRIFT,L=.30
               HILC:DRIFT,L=.30
               HILD:DRIFT,L=.30
               HILE:DRIFT,L=1.5
               HILF:DRIFT,L=.5
               HILG:DRIFT,L=3.0
               HILH:DRIFT,L=.40
               HILI:DRIFT,L=1.30
               HILJ:DRIFT,L=.40
               HILK:DRIFT,L=1.70
               HILL:DRIFT,L=.50
               HILM:DRIFT,L=.3
               HILN:DRIFT,L=1.0


               HIDC:SBEND,L=.450,ANGLE=-.34906585,TILT=.11017
               HIDB:SBEND,L=.450,ANGLE=.34906585,TILT=.110170
               HIDA:SBEND,L=.450,ANGLE=.34906585,TILT=0

               HIQFA:QUAD,L=.150,K1=3.01531400678
               HIQFB:QUAD,L=.150,K1=2.97376034875
               HIQFC:QUAD,L=.150,K1=3.49999999916
               HIQFD:QUAD,L=.150,K1=1.987117

               HIQDA:QUAD,L=.150,K1=-1.08624681663
               HIQDB:QUAD,L=.150,K1=0
               HIQDC:QUAD,L=.150,K1=-2.0000
               HIQDD:QUAD,L=.150,K1=-2.96600878394
               HIQDE:QUAD,L=.1500,K1=-3.1999999
               HIQDF:QUAD,L=.150,K1=-2.00000
               HIQDG:QUAD,L=.150,K1=-1.46334111601

               HIBST:LINE=(2*HIDC,HILM,2*HIQDG,HILN,2*HIKICK,MDR,MQFC3)
               HINTER:LINE=(HILD,2*HIQDC,HILE,2*HIQFA,HILF,2*HIQDD,HILG,2*HIQFB,HILH,&
                     2*HIQDE,HILI,2*HIQFC,HILJ,2*HIQDF,HILK,2*HIQFD,HILL)
               HILINC:LINE=(HIQDA,HILA,2*HIDA,HILB,2*HIQDB,HILC,2*HIDB)
               HILINE:LINE=(HILINC,HINTER,HIBST)

               USE,HILINE
```

DELTA(P)/P = 0.000000 SYMM = F

POS. NO.	ELEMENT NAME	SEQUENCE OCC. NO.	DIST [M]	I I	HORIZONTAL BETAX [M]	ALFAX [1]	MUX [2PI]	X(CO) [MM]	PX(CO) [.001]	DX [M]	DPX [1]	I I	VERTICAL BETAY [M]	ALFAY [1]	MUY [2PI]	Y(CO) [MM]	PY(CO) [.001]	DY [M]	DPY [1]
BEGIN	HILINE	1	0.000		3.875	3.191	0.000	0.000	0.000	0.000	0.000		12.322	0.401	0.000	0.000	0.000	0.000	0.000
BEGIN	HILINC	1	0.000		3.875	3.191	0.000	0.000	0.000	0.000	0.000		12.322	0.401	0.000	0.000	0.000	0.000	0.000
1	HIQDA	1	0.150		3.063	2.267	0.007	0.000	0.000	0.000	0.000		11.907	2.343	0.002	0.000	0.000	0.000	0.000
2	HILA	1	2.150		2.012	-1.741	0.358	0.000	0.000	0.000	0.000		4.716	1.253	0.045	0.000	0.000	0.000	0.000
3	HIDA	1	2.600		3.608	-1.662	0.384	0.000	0.000	0.078	0.342		3.698	1.008	0.062	0.000	0.000	0.000	0.000
4	HIDA	2	3.050		4.767	-0.806	0.401	0.000	0.000	0.302	0.643		2.902	0.762	0.084	0.000	0.000	0.000	0.000
5	HILB	1	3.350		5.281	-0.910	0.410	0.000	0.000	0.494	0.643		2.493	0.599	0.102	0.000	0.000	0.000	0.000
6	HIQDB	1	3.500		5.562	-0.962	0.415	0.000	0.000	0.591	0.643		2.326	0.517	0.112	0.000	0.000	0.000	0.000
7	HIQDB	2	3.650		5.858	-1.014	0.419	0.000	0.000	0.687	0.643		2.183	0.435	0.122	0.000	0.000	0.000	0.000
8	HILC	1	3.950		6.497	-1.117	0.427	0.000	0.000	0.880	0.643		1.971	0.272	0.145	0.000	0.000	0.000	0.000
9	HIDB	1	4.400		6.740	0.599	0.437	0.000	0.000	1.188	0.714		1.834	0.033	0.184	0.000	0.000	0.002	0.008
10	HIDB	2	4.850		5.504	2.038	0.449	0.000	0.000	1.510	0.700		1.912	-0.207	0.222	0.000	0.000	0.006	0.006
END	HILINC	1	4.850		5.504	2.038	0.449	0.000	0.000	1.510	0.700		1.912	-0.207	0.222	0.000	0.000	0.006	0.006
BEGIN	HINTER	1	4.850		5.504	2.038	0.449	0.000	0.000	1.510	0.700		1.912	-0.207	0.222	0.000	0.000	0.006	0.006
11	HILD	1	5.150		4.365	1.757	0.459	0.000	0.000	1.720	0.700		2.086	-0.371	0.246	0.000	0.000	0.008	0.006
12	HIQDC	1	5.300		4.043	0.424	0.464	0.000	0.000	1.864	1.235		2.113	0.190	0.257	0.000	0.000	0.008	0.004
13	HIQDC	2	5.450		4.103	-0.832	0.470	0.000	0.000	2.093	1.826		1.975	0.717	0.269	0.000	0.000	0.009	0.001
14	HILE	1	6.950		7.526	-1.450	0.514	0.000	0.000	4.833	1.826		1.549	-0.433	0.433	0.000	0.000	0.011	0.001
15	HIQFA	1	7.100		7.452	1.935	0.517	0.000	0.000	4.940	-0.396		1.810	-1.346	0.447	0.000	0.000	0.011	0.006
16	HIQFA	2	7.250		6.417	4.807	0.520	0.000	0.000	4.715	-2.592		2.394	-2.633	0.459	0.000	0.000	0.013	0.012
17	HILF	1	7.750		2.549	2.929	0.540	0.000	0.000	3.419	-2.592		5.855	-4.289	0.480	0.000	0.000	0.018	0.012
18	HIQDD	1	7.900		1.891	1.554	0.551	0.000	0.000	3.140	-1.141		6.776	-1.714	0.484	0.000	0.000	0.020	0.003
19	HIQDD	2	8.050		1.574	0.604	0.565	0.000	0.000	3.073	0.233		6.838	1.309	0.488	0.000	0.000	0.019	-0.006
20	HILG	1	11.050		5.752	-1.996	0.828	0.000	0.000	3.773	0.233		2.557	0.119	0.615	0.000	0.000	0.003	-0.006
21	HIQFB	1	11.200		5.967	0.593	0.832	0.000	0.000	3.682	-1.439		2.703	-1.119	0.624	0.000	0.000	0.002	-0.005
22	HIQFB	2	11.350		5.411	3.028	0.836	0.000	0.000	3.346	-3.015		3.258	-2.663	0.632	0.000	0.000	0.001	-0.004
23	HILH	1	11.750		3.290	2.276	0.851	0.000	0.000	2.140	-3.015		5.787	-3.657	0.647	0.000	0.000	0.000	-0.004
24	HIQDE	1	11.900		2.859	0.660	0.859	0.000	0.000	1.760	-2.084		6.480	-0.852	0.651	0.000	0.000	-0.001	-0.004
25	HIQDE	2	12.050		2.874	-0.761	0.867	0.000	0.000	1.507	-1.305		6.274	2.193	0.655	0.000	0.000	-0.001	-0.003
26	HILI	1	13.350		5.780	-1.474	0.919	0.000	0.000	-0.190	-1.305		2.137	0.989	0.712	0.000	0.000	-0.005	-0.003
27	HIQFC	1	13.500		5.768	1.551	0.923	0.000	0.000	-0.375	-1.156		2.018	-0.179	0.724	0.000	0.000	-0.006	-0.006
28	HIQFC	2	13.650		4.897	4.101	0.927	0.000	0.000	-0.532	-0.916		2.249	-1.404	0.735	0.000	0.000	-0.007	-0.009
29	HILJ	1	14.050		2.199	2.646	0.947	0.000	0.000	-0.898	-0.916		3.584	-1.933	0.758	0.000	0.000	-0.011	-0.009
30	HIQDF	1	14.200		1.564	1.645	0.960	0.000	0.000	-1.057	-1.208		4.017	-0.910	0.764	0.000	0.000	-0.012	-0.006
31	HIQDF	2	14.350		1.181	0.946	0.978	0.000	0.000	-1.263	-1.555		4.114	0.273	0.770	0.000	0.000	-0.013	-0.002
32	HILK	1	16.050		2.600	-1.781	1.267	0.000	0.000	-3.907	-1.555		3.940	-0.171	0.839	0.000	0.000	-0.016	-0.002
33	HIQFD	1	16.200		3.040	-1.105	1.275	0.000	0.000	-4.051	-0.365		4.177	-1.436	0.845	0.000	0.000	-0.017	-0.007
34	HIQFD	2	16.350		3.244	-0.235	1.283	0.000	0.000	-4.015	0.842		4.827	-2.962	0.851	0.000	0.000	-0.019	-0.013
35	HILL	1	16.850		3.560	-0.397	1.306	0.000	0.000	-3.594	0.842		8.296	-3.975	0.863	0.000	0.000	-0.025	-0.013
END	HINTER	1	16.850		3.560	-0.397	1.306	0.000	0.000	-3.594	0.842		8.296	-3.975	0.863	0.000	0.000	-0.025	-0.013
BEGIN	HIBST	1	16.850		3.560	-0.397	1.306	0.000	0.000	-3.594	0.842		8.296	-3.975	0.863	0.000	0.000	-0.025	-0.013
36	HIDC	1	17.300		3.541	0.437	1.326	0.000	0.000	-3.086	1.395		12.267	-4.847	0.870	0.000	0.000	-0.016	0.049
37	HIDC	2	17.750		2.835	1.069	1.348	0.000	0.000	-2.364	1.781		17.011	-5.691	0.875	0.000	0.000	0.016	0.091
38	HILM	1	18.050		2.261	0.842	1.367	0.000	0.000	-1.830	1.781		20.603	-6.280	0.878	0.000	0.000	0.043	0.091
39	HIQDG	1	18.200		2.095	0.275	1.378	0.000	0.000	-1.591	1.406		21.818	-1.735	0.879	0.000	0.000	0.056	0.080
40	HIQDG	2	18.350		2.092	-0.255	1.390	0.000	0.000	-1.406	1.078		21.621	3.036	0.880	0.000	0.000	0.067	0.067
41	HILN	1	19.350		3.112	-0.764	1.454	0.000	0.000	-0.327	1.078		16.022	2.563	0.889	0.000	0.000	0.134	0.067
42	HIKICK	1	20.950		6.693	-1.450	1.511	0.000	0.000	1.251	0.888		9.030	1.807	0.910	0.000	0.000	0.241	0.067
43	HIKICK	2	22.550		12.194	-1.950	1.539	0.000	0.000	2.501	0.670		4.456	1.051	0.950	0.000	0.000	0.347	0.067
44	MDR	1	22.850		13.400	-2.069	1.542	0.000	0.000	2.702	0.670		3.868	0.910	0.962	0.000	0.000	0.367	0.067
45	MQFC3	1	23.100		13.976	-0.208	1.545	0.000	0.000	2.821	0.286		3.568	0.304	0.973	0.000	0.000	0.391	0.119
END	HIBST	1	23.100		13.976	-0.208	1.545	0.000	0.000	2.821	0.286		3.568	0.304	0.973	0.000	0.000	0.391	0.119
END	HILINE	1	23.100		13.976	-0.208	1.545	0.000	0.000	2.821	0.286		3.568	0.304	0.973	0.000	0.000	0.391	0.119

TOTAL LENGTH	=	23.100000	MUX	=	1.545331	MUY	=	0.972635
DELTA(S)	=	0.000000 mm	DMUX	=	-1.484248	DMUY	=	-0.240087
			BETAX(MAX)	=	13.975694	BETAY(MAX)	=	21.818149
			DX(MAX)	=	4.940430	DY(MAX)	=	0.390587

WARNING ## TWISS1: TWISS PARAMETERS FOR DELTA(P)/P = 0.00000000 MAY BE WRONG DUE TO COUPLING.

WARNING ## TWISS1: TWISS PARAMETERS FOR DELTA(P)/P = 0.00000000 MAY BE WRONG DUE TO COUPLING.

TABLE 2

```
BOOS  RUN
MDR   DRF        0.30
LA    DRF        2.00
LB    DRF        0.30
LC    DRF        0.30
LD    DRF        0.30
LE    DRF        1.50
LF    DRF        0.50
LG    DRF        3.00
LH    DRF        0.40
LI    DRF        1.30
LJ    DRF        0.40
LK    DRF        1.70
LL    DRF        0.50
LM    DRF        0.30
LN    DRF        1.00
R+    ROTZ       6.31228
R-    ROTZ       -6.31228
DB    MAG        0.45       0.0        0.45       .3490659  0          0
DBR   MMM        R-   DB    R+
R+    ROTZ       6.31228
R-    ROTZ       -6.31228
DC    MAG        0.45       0.0        0.45       .3490659  0          0
DCR   MMM        R-   DC    R+
DA    MAG        0.45       0.0        0.45       -.3490659 0          0
CK    MAG        1.6        0.0        1.6        -.180056  0          0

KFA   =          .45229710
KFB   =          .44606405
KFC   =          .52500000
KFD   =          .29806755
KDA   =          -.1629370
KDB   =          .000000000
KDC   =          -.30000000
KDD   =          -.44490132
KDE   =          -.47999999
KDF   =          -.30000000
KDG   =          -.21950117

BET0  IBET       0          3.875      3.191      2.8858    0          0
                 0          12.232     0.401      .0948987  0          0
BO    SUB
FC3   MAG        .25        0.1386423  .25        0         0          0
FA    MAG        .15        KFA        .15        0         0          0
FB    MAG        .15        KFB        .15        0         0          0
FC    MAG        .15        KFC        .15        0         0          0
FD    MAG        .15        KFD        .15        0         0          0

QDA   MAG        .15        KDA        .15        0         0          0
QDB   MAG        .15        KDB        .15        0         0          0
QDC   MAG        .15        KDC        .15        0         0          0
QDD   MAG        .15        KDD        .15        0         0          0
QDE   MAG        .15        KDE        .15        0         0          0
QDF   MAG        .15        KDF        .15        0         0          0
QDG   MAG        .15        KDG        .15        0         0          0

BST   BML        DCR  DCR   LM   QDG   QDG   LN
                 CK   CK    MDR  FC3
NTER  BML        LD   QDC   QDC  LE    FA    FA    LF   QDD   QDD   LG
                 FB   FB    LH   QDE   QDE   LI    FC   FC    LJ    QDF
```

```
                QDF  LK   FD   FD   LL
LINC  BML       QDA  LA   DA   DA   LB   QDB  QDB  LC   DBR  DBR

LIN   BML       LINC NTER BST
```

Table 3.

SYNCH VERSIONIBM 3090

SYNCH RUN BOOS
29-APR-91 11:00:07

POS		S	QX	BX	AX	X	DX	QY	BY	AY	Y	DY
0		0.0000	0.000000	3.8750	3.191000	0.000000	0.000000	0.000000	12.2320	0.401000	0.000000	0.000000
1	QDA	0.1500	0.006960	3.0630	2.266578	0.000000	0.000000	0.001977	11.8192	2.328284	0.000000	0.000000
2	LA	2.1500	0.357847	2.0116	-1.740888	0.000000	0.000000	0.045314	4.6791	1.241766	0.000000	0.000000
3	DA	2.6000	0.384011	3.6084	-1.662296	0.077746	0.342020	0.062627	3.6716	0.997300	0.000000	0.000000
4	DA	3.0500	0.400964	4.7665	-0.805898	0.301605	0.642788	0.084707	2.8840	0.752833	0.000000	0.000000
5	LB	3.3500	0.410486	5.2812	-0.909713	0.494441	0.642788	0.102594	2.4812	0.589856	0.000000	0.000000
6	QDB	3.5000	0.414892	5.5619	-0.961621	0.590859	0.642788	0.112558	2.3165	0.508367	0.000000	0.000000
7	QDB	3.6500	0.419074	5.8582	-1.013529	0.687278	0.642788	0.123199	2.1762	0.426878	0.000000	0.000000
8	LC	3.9500	0.426817	6.4974	-1.117345	0.880114	0.642788	0.146347	1.9689	0.263901	0.000000	0.000000
9	DBR	4.4000	0.437431	6.7404	0.598969	1.188439	0.713761	0.184338	1.8387	0.025217	-0.008548	-0.037604
10	DBR	4.8500	0.448965	5.5036	2.038287	1.509696	0.699695	0.222784	1.9235	-0.213606	-0.034007	-0.075154
11	LD	5.1500	0.458713	4.3649	1.757312	1.719604	0.699695	0.246626	2.1006	-0.376676	-0.056553	-0.075154
12	QDC	5.3000	0.464440	4.0425	0.424014	1.864184	1.235257	0.257839	2.1292	0.189059	-0.066474	-0.056630
13	QDC	5.4500	0.470348	4.1028	-0.831810	2.092967	1.826613	0.269359	1.9906	0.721270	-0.073415	-0.035567
14	LE	6.9500	0.513850	7.5260	-1.450359	4.832887	1.826613	0.432675	1.5451	-0.424267	-0.126766	-0.035567
15	FA	7.1000	0.517002	7.4516	1.935044	4.940774	-0.396268	0.447161	1.8030	-1.333817	-0.136487	-0.094767
16	FA	7.2500	0.520416	6.4168	4.807087	4.715346	-2.592416	0.458822	2.3820	-2.613597	-0.155519	-0.160433
17	LF	7.7500	0.540143	2.5490	2.928578	3.419139	-2.592416	0.480263	5.8175	-4.257323	-0.235736	-0.160433
18	QDD	7.9000	0.551147	1.8911	1.554099	3.140661	-1.141245	0.484037	6.7313	-1.698507	-0.251712	-0.051393
19	QDD	8.0500	0.565154	1.5745	0.603782	3.072944	0.233339	0.487528	6.7919	1.303714	-0.250983	0.061058
20	LG	11.0500	0.827695	5.7515	-1.996129	3.772962	0.233339	0.615756	2.5469	0.111282	-0.067810	0.061058
21	FB	11.2000	0.831726	5.9667	0.593434	3.682053	-1.438701	0.624975	2.6954	-1.123236	-0.060830	0.032526
22	FB	11.3500	0.835881	5.4111	3.027682	3.346149	-3.015014	0.633133	3.2513	-2.665140	-0.057943	0.006182
23	LH	11.7500	0.850993	3.2896	2.276133	2.140143	-3.015014	0.647837	5.7821	-3.662028	-0.055470	0.006182
24	QDE	11.9000	0.858874	2.8594	0.660390	1.759953	-2.084567	0.651692	6.4771	-0.859260	-0.052569	0.032268
25	QDE	12.0500	0.867306	2.8741	-0.760552	1.507242	-1.305111	0.655392	6.2733	2.185092	-0.045905	0.056045
26	LI	13.3500	0.918974	5.7796	-1.474486	-0.189403	-1.305111	0.713010	2.1477	0.988445	0.026953	0.056045
27	FC	13.5000	0.923055	5.7678	1.551078	-0.375201	-1.155922	0.724603	2.0302	-0.184869	0.036539	0.072603
28	FC	13.6500	0.927489	4.8971	4.100744	-0.531646	-0.916300	0.735893	2.2646	-1.417962	0.049021	0.094916
29	LJ	14.0500	0.946939	2.1986	2.645500	-0.898166	-0.916300	0.758227	3.6116	-1.949733	0.086988	0.094916
30	QDF	14.2000	0.959923	1.5644	1.645418	-1.056929	-1.208470	0.764425	4.0485	-0.919083	0.099169	0.066888
31	QDF	14.3500	0.977652	1.1814	0.945980	-1.263432	-1.555225	0.770210	4.1467	0.274535	0.106904	0.035860
32	LK	16.0500	1.266795	2.6002	-1.780546	-3.907314	-1.555225	0.839085	3.9627	-0.166306	0.167867	0.035860
33	FD	16.2000	1.275227	3.0396	-1.105021	-4.051840	-0.364602	0.844982	4.1998	-1.438141	0.177052	0.087074
34	FD	16.3500	1.282777	3.2436	-0.234802	-4.015882	0.842261	0.850311	4.8515	-2.971031	0.194184	0.142196
35	LL	16.8500	1.306281	3.5597	-0.397439	-3.594752	0.842261	0.862842	8.3289	-3.983800	0.265282	0.142196
36	DCR	17.3000	1.326102	3.5411	0.436955	-3.086397	1.394313	0.869916	12.3087	-4.856158	0.337609	0.178846
37	DCR	17.7500	1.348329	2.8347	1.069289	-2.364859	1.780236	0.874858	17.0613	-5.700464	0.426372	0.215237
38	LM	18.0500	1.367232	2.2612	0.842467	-1.830789	1.780236	0.877402	20.6583	-6.289433	0.490943	0.215237
39	QDG	18.2000	1.378269	2.0953	0.275338	-1.592508	1.405554	0.878519	21.8749	-1.732228	0.514991	0.104531
40	QDG	18.3500	1.389743	2.0923	-0.255130	-1.406805	1.077278	0.879609	21.6749	3.050619	0.522130	-0.009607
41	LN	19.3500	1.453836	3.1116	-0.764114	-0.329526	1.077278	0.888146	16.0492	2.575131	0.512523	-0.009607
42	CK	20.9500	1.510525	6.6934	-1.450294	1.246492	0.887419	0.909367	9.0260	1.814351	0.497152	-0.009607
43	CK	22.5500	1.538706	12.1941	-1.950423	2.494895	0.668867	0.950045	4.4373	1.053571	0.481780	-0.009607
44	MDR	22.8500	1.542442	13.3999	-2.068612	2.695555	0.668867	0.961611	3.8480	0.910925	0.478898	-0.009607
45	FC3	23.1000	1.545333	13.9757	-0.207937	2.815228	0.285746	0.972451	3.5469	0.307260	0.484806	0.057006

TABLE 5.

```
MQFC3:QUAD,L=0.25,K1=.554569
MDR:DRIFT,L=.30
HIKICK:SBEND,L=1.6,ANGLE=-.180056

HILA:DRIFT,L=1.45
HILB:DRIFT,L=.40
HILC:DRIFT,L=.30
HILD:DRIFT,L=.50
HILE:DRIFT,L=2.80
HILF:DRIFT,L=.20
HILG:DRIFT,L=.90

HIDC:SBEND,L=.450,ANGLE=-.34906585,TILT=.11017
HIDB:SBEND,L=.450,ANGLE=.34906585,TILT=.11017
HIDA:SBEND,L=.450,ANGLE=.34906585

HIQFA:QUAD,L=.150,K1=.5003568
HIQFB:QUAD,L=.150,K1=1.991593
HIQFC:QUAD,L=.150,K1=.7359442
HIQFD:QUAD,L=.150,K1=2.228046
HIQFE:QUAD,L=.150,K1=9.700261

HIQDA:QUAD,L=.150,K1=-.4770799
HIQDB:QUAD,L=.150,K1=-.1155274
HIQDC:QUAD,L=.150,K1=-3.038158
HIQDD:QUAD,L=.150,K1=-6.512461

HIBST:LINE=(2*HIDC,HILF,HIQFE,HILF,HIQDD,HILG,2*HIKICK,MDR,MQFC3)
HINTER:LINE=(HILD,2*HIQDB,HILD,2*HIQFC,HILD,2*HIQDC,HILD,2*HIQFD,&
      2*HILE,2*HIQFD,HILD,2*HIQDC,HILD,2*HIQFC,HILD,2*HIQDB,HILD)
HILINC:LINE=(HIQDA,HILA,HIQFA,HILB,2*HIDA,HILC,2*HIQFB,HILC,2*HIDB)
HILINE:LINE=(HILINC,HINTER,HIBST)
```

DELTA(P)/P = 0.000000 SYMM = F

POS. NO.	ELEMENT NAME	SEQUENCE OCC. NO.	DIST [M]	I I	HORIZONTAL BETAX [M]	ALFAX [1]	MUX [2PI]	X(CO) [MM]	PX(CO) [.001]	DX [M]	DPX [1]	I I	VERTICAL BETAY [M]	ALFAY [1]	MUY [2PI]	Y(CO) [MM]	PY(CO) [.001]	DY [M]	DPY [1]
BEGIN	HILINE	1	0.000		3.875	3.191	0.000	0.000	0.000	0.000	0.000		12.322	0.401	0.000	0.000	0.000	0.000	0.000
BEGIN	HILINC	1	0.000		3.875	3.191	0.000	0.000	0.000	0.000	0.000		12.322	0.401	0.000	0.000	0.000	0.000	0.000
1	HIQDA	1	0.150		3.018	2.544	0.007	0.000	0.000	0.000	0.000		12.073	1.254	0.002	0.000	0.000	0.000	0.000
2	HILA	1	1.600		0.846	-1.047	0.326	0.000	0.000	0.000	0.000		8.885	0.945	0.024	0.000	0.000	0.000	0.000
3	HIQFA	1	1.750		1.204	-1.329	0.350	0.000	0.000	0.000	0.000		8.704	0.262	0.027	0.000	0.000	0.000	0.000
4	HILB	1	2.150		2.635	-2.248	0.386	0.000	0.000	0.000	0.000		8.514	0.213	0.034	0.000	0.000	0.000	0.000
5	HIDA	1	2.600		4.636	-2.017	0.406	0.000	0.000	0.078	0.342		8.347	0.158	0.043	0.000	0.000	0.000	0.000
6	HIDA	2	3.050		5.978	-0.843	0.419	0.000	0.000	0.302	0.643		8.230	0.103	0.052	0.000	0.000	0.000	0.000

7	HILC	1	3.350	6.510	-0.928	0.427	0.000	0.000	0.494	0.643	8.179	0.066	0.057	0.000	0.000	0.000	0.000
8	HIQFB	1	3.500	6.499	0.999	0.431	0.000	0.000	0.579	0.482	8.534	-2.464	0.060	0.000	0.000	0.000	0.000
9	HIQFB	2	3.650	5.928	2.750	0.434	0.000	0.000	0.638	0.299	9.702	-5.443	0.063	0.000	0.000	0.000	0.000
10	HILC	2	3.950	4.408	2.317	0.444	0.000	0.000	0.728	0.299	13.252	-6.390	0.067	0.000	0.000	0.000	0.000
11	HIDB	1	4.400	2.258	2.268	0.466	0.000	0.000	0.894	0.431	19.617	-7.748	0.072	0.000	0.000	0.003	0.015
12	HIDB	2	4.850	0.644	1.171	0.526	0.000	0.000	1.108	0.511	27.184	-9.061	0.075	0.000	0.000	0.012	0.023
END	HILINC	1	4.850	0.644	1.171	0.526	0.000	0.000	1.108	0.511	27.184	-9.061	0.075	0.000	0.000	0.012	0.023
BEGIN	HINTER	1	4.850	0.644	1.171	0.526	0.000	0.000	1.108	0.511	27.184	-9.061	0.075	0.000	0.000	0.012	0.023
13	HILD	1	5.350	0.393	-0.669	0.757	0.000	0.000	1.363	0.511	37.009	-10.589	0.077	0.000	0.000	0.024	0.023
14	HIQDB	1	5.500	0.678	-1.233	0.804	0.000	0.000	1.441	0.535	40.153	-10.352	0.078	0.000	0.000	0.027	0.023
15	HIQDB	2	5.650	1.134	-1.809	0.831	0.000	0.000	1.523	0.561	43.209	-10.007	0.078	0.000	0.000	0.031	0.022
16	HILD	2	6.150	3.885	-3.692	0.870	0.000	0.000	1.804	0.561	53.801	-11.177	0.080	0.000	0.000	0.042	0.022
17	HIQFC	1	6.300	5.000	-3.705	0.875	0.000	0.000	1.873	0.357	58.140	-17.909	0.080	0.000	0.000	0.046	0.027
18	HIQFC	2	6.450	6.083	-3.474	0.879	0.000	0.000	1.911	0.148	64.665	-25.834	0.081	0.000	0.000	0.050	0.033
19	HILD	3	6.950	10.095	-4.548	0.889	0.000	0.000	1.985	0.148	93.083	-31.002	0.082	0.000	0.000	0.066	0.033
20	HIQDC	1	7.100	12.278	-10.335	0.892	0.000	0.000	2.076	1.068	95.974	12.173	0.082	0.000	0.000	0.069	0.001
21	HIQDC	2	7.250	16.582	-19.012	0.893	0.000	0.000	2.309	2.062	86.107	52.095	0.082	0.000	0.000	0.067	-0.030
22	HILD	4	7.750	41.058	-29.941	0.896	0.000	0.000	3.340	2.062	41.895	36.331	0.084	0.000	0.000	0.052	-0.030
23	HIQFD	1	7.900	48.203	-16.891	0.897	0.000	0.000	3.563	0.903	33.484	20.671	0.084	0.000	0.000	0.049	-0.013
24	HIQFD	2	8.050	50.858	-0.510	0.897	0.000	0.000	3.608	-0.300	29.073	9.227	0.085	0.000	0.000	0.048	0.003
25	HILE	1	10.850	53.910	-0.580	0.906	0.000	0.000	2.768	-0.300	0.630	0.931	0.199	0.000	0.000	0.057	0.003
26	HILE	2	13.650	57.351	-0.649	0.914	0.000	0.000	1.928	-0.300	18.641	-7.364	0.546	0.000	0.000	0.067	0.003
27	HIQFD	3	13.800	54.712	17.944	0.914	0.000	0.000	1.835	-0.932	21.943	-15.014	0.548	0.000	0.000	0.069	0.026
28	HIQFD	4	13.950	46.940	32.999	0.915	0.000	0.000	1.651	-1.516	27.954	-25.726	0.549	0.000	0.000	0.074	0.050
29	HILD	5	14.450	19.746	21.389	0.917	0.000	0.000	0.892	-1.516	59.608	-37.582	0.551	0.000	0.000	0.099	0.050
30	HIQDC	3	14.600	14.949	11.322	0.919	0.000	0.000	0.693	-1.157	66.915	-10.013	0.551	0.000	0.000	0.103	0.003
31	HIQDC	4	14.750	12.639	4.422	0.921	0.000	0.000	0.541	-0.878	65.346	20.232	0.551	0.000	0.000	0.100	-0.043
32	HILD	6	15.250	8.623	3.609	0.928	0.000	0.000	0.102	-0.878	46.684	17.092	0.553	0.000	0.000	0.079	-0.043
33	HIQFC	3	15.400	7.447	4.190	0.931	0.000	0.000	-0.030	-0.882	42.419	11.498	0.553	0.000	0.000	0.073	-0.035
34	HIQFC	4	15.550	6.137	4.496	0.935	0.000	0.000	-0.161	-0.871	39.708	6.670	0.554	0.000	0.000	0.068	-0.027
35	HILD	7	16.050	2.505	2.768	0.955	0.000	0.000	-0.597	-0.871	33.324	6.098	0.556	0.000	0.000	0.054	-0.027
36	HIQDB	3	16.200	1.758	2.219	0.966	0.000	0.000	-0.728	-0.883	31.437	6.471	0.557	0.000	0.000	0.050	-0.028
37	HIQDB	4	16.350	1.171	1.694	0.983	0.000	0.000	-0.862	-0.896	29.449	6.777	0.558	0.000	0.000	0.046	-0.029
38	HILD	8	16.850	0.303	0.043	1.141	0.000	0.000	-1.310	-0.896	23.070	5.980	0.561	0.000	0.000	0.031	-0.029
END	HINTER	1	16.850	0.303	0.043	1.141	0.000	0.000	-1.310	-0.896	23.070	5.980	0.561	0.000	0.000	0.031	-0.029
BEGIN	HIBST	1	16.850	0.303	0.043	1.141	0.000	0.000	-1.310	-0.896	23.070	5.980	0.561	0.000	0.000	0.031	-0.029
39	HIDC	1	17.300	0.875	-1.262	1.305	0.000	0.000	-1.705	-0.840	17.982	5.320	0.564	0.000	0.000	0.019	-0.023
40	HIDC	2	17.750	2.397	-1.983	1.354	0.000	0.000	-2.051	-0.684	13.502	4.630	0.569	0.000	0.000	0.013	-0.006
41	HILF	1	17.950	3.273	-2.395	1.366	0.000	0.000	-2.188	-0.684	11.717	4.298	0.571	0.000	0.000	0.011	-0.006
42	HIQFE	1	18.100	3.271	2.410	1.373	0.000	0.000	-2.052	2.458	13.020	-13.612	0.573	0.000	0.000	0.012	0.011
43	HILF	2	18.300	2.390	1.994	1.384	0.000	0.000	-1.561	2.458	19.037	-16.474	0.575	0.000	0.000	0.014	0.011
44	HIQDD	1	18.450	2.148	-0.306	1.395	0.000	0.000	-1.298	1.078	21.161	3.013	0.576	0.000	0.000	0.015	-0.003
45	HILG	1	19.350	3.111	-0.764	1.451	0.000	0.000	-0.328	1.078	16.124	2.584	0.584	0.000	0.000	0.012	-0.003
46	HIKICK	1	20.950	6.693	-1.450	1.508	0.000	0.000	1.250	0.889	9.073	1.822	0.605	0.000	0.000	0.007	-0.003
47	HIKICK	2	22.550	12.194	-1.950	1.536	0.000	0.000	2.500	0.670	4.460	1.060	0.646	0.000	0.000	0.002	-0.003
48	MDR	1	22.850	13.400	-2.069	1.540	0.000	0.000	2.701	0.670	3.867	0.917	0.657	0.000	0.000	0.001	-0.003
49	MQFC3	1	23.100	13.976	-0.208	1.543	0.000	0.000	2.821	0.286	3.563	0.311	0.668	0.000	0.000	0.000	-0.003
END	HIBST	1	23.100	13.976	-0.208	1.543	0.000	0.000	2.821	0.286	3.563	0.311	0.668	0.000	0.000	0.000	-0.003
END	HILINE	1	23.100	13.976	-0.208	1.543	0.000	0.000	2.821	0.286	3.563	0.311	0.668	0.000	0.000	0.000	-0.003

TOTAL LENGTH =	23.100000	MUX =	1.542899	MUY =	0.668082
DELTA(S) =	0.000000 mm	DMUX =	-4.581355	DMUY =	-4.558858
		BETAX(MAX) =	57.350592	BETAY(MAX) =	95.973602
		DX(MAX) =	3.608452	DY(MAX) =	0.103290

WARNING ## TWISS1: TWISS PARAMETERS FOR DELTA(P)/P = 0.00000000 MAY BE WRONG DUE TO COUPLING.

WARNING ## TWISS1: TWISS PARAMETERS FOR DELTA(P)/P = 0.00000000 MAY BE WRONG DUE TO COUPLING.