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Alternate AGS - Booster lattices

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ALTERNATE AGS - BOOSTER LATTICES

Booster Technical Note

No. 32

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ABSTRACT

WE HAVE STUDIED THE ALTERNATE CONCEPTUAL LATTICES FOR THE AGS - BOOSTER. WE PRESENT SOME OF OUR RESULTS FOR THE STANDARD BOOSTER LATTICE AND THE ALTERNATE [1/4 AGS, P=12] COMBINED, HYBRID AND [1/3 AGS, P = 8] SEPARATED FUNCTION LATTICES. WE INCLUDE OUR CALCULATION AND ANALYSIS OF THE STOP BANDWIDTHS FOR THE THIRD ORDER RESONANCES OF THESE LATTICES.

INTRODUCTION:

We have studied the nonlinear effects of the AGS-Booster lattice [1,2] and its alternates. In our investigation of the nonlinear effects for the present Booster lattice in addition to the third order structure resonances given in Section V, we have calculated the fourth order resonances given elsewhere [3,4]. These resonances are crossed at injection because of the space charge effect since the Laslett tune shift may be as large as 1. This has led to our investigation of the following [1/4 AGS, P = 12] combined, hybrid and [1/3 AGS, P = 8] separated function lattices given in Figs. 1-3. In section two we discuss the general treatment of the nonlinear effects following Guignard [5] and Donald [6]. In Sections three and four using program HARMON (MAD403) the nonlinear effects of these alternative lattices are analyzed and given in tables I-III. With space charge tune shifts as large as 1 the third order resonances may be crossed.

The sixth order resonances are important and we will discuss them in subsequent papers using program NONLIN [4] (since HARMON is not equipped to do so). We have used B" = .24 T/m for the eddy current sextupoles.

SECTION II

To study the dynamics of an accelerator with chromaticity correcting sextupoles and eddy current sextupoles, we have used the following Hamiltonian [1]:

$$H0= \frac{1}{2}\left(p_x^{\,2}+ p_y^{\,2}\right) + \left(\frac{1}{\rho^2} - K(s)\right)\frac{x^2}{2} + K(s)\,\frac{y^2}{2} + \frac{S(s)}{6}\left(x^3 - 3xy^2\right) \qquad (1)$$

where, x and y are the positions, p_x and p_y are the conjugate momentum, K is the quadrupole focussing strength, S is the sextupole strength, and s is the distance along the orbit (the "time" variable for the Hamiltonian).

First we transform the Hamiltonian to action - angle form:

$$H1= \frac{2\pi}{C}\left(Q_x J_x + Q_y J_y\right) + V(J_x, J_y, \phi_x, \phi_y, s) \qquad (2)$$

where, C is the circumference; Jx, Jy are the action variables (directly related to the beam emittances); ϕ x, ϕ y are the angle variables and Qx, Qy are the betatron tunes.

When the system is operating near a resonance, perturbation theory no longer holds. Although, an approximate invariant can be found for system near a single resonance if the contribution from the other resonances are small. This can lead to the Hamiltonian

$$H2= \frac{2\pi}{C} e K_x + \sum_{\ell=1} W_\ell K_x^{\frac{\ell}{2}+1} + A \cos \Psi_X \qquad (3)$$

where, e is the bandwidth given in eq. (4); Kx and Ky are the new action variables and ψ_x is the transformed angle. W_ℓ are the stablizing coefficients and A is the resonance strength. This Hamiltonian is an invariant of the motion.

$$e = Nx\ Qx + Ny\ Qy - p \qquad (4)$$

where the integers Nx, Ny and p define a given resonance.

Following Guignard [5], dynamic properties (such as stop bandwidths, Δe) can be found from invariant of the motion H2. The stop bandwidths (Δe) are defined to be the smallest bandwidth such that the action in Eq. (3) is still bounded. This can be done by first considering the fixed points of Eq. (3) which are defined to be the points at which there is no motion. These fixed points are the solutions to the following equations (note that Ky is also an invariant of the motion and can be treated as a constant).

$$0 = \frac{d\psi_x}{ds} = \frac{\partial H_2}{\partial K_x} \qquad (5a)$$

$$= \frac{2\pi}{C} e + \sum_{\ell=1} \left(\frac{\ell}{2}+1\right) W_\ell K_x^{\frac{\ell}{2}} + \frac{\partial A}{\partial K_x} \cos \psi_x$$

$$0 = \frac{d K_x}{d s} = - \frac{\partial H_2}{\partial \psi_x} = A \sin \psi_x \qquad (5b)$$

There are many solutions $[\psi_x = n\pi]$ to eq. (5b) which lead to two cases $[\cos(\psi_x) = \pm 1]$ in eq. (5a). We note that for the smallest positive value of Kx there is at most one solution for each of these cases corresponding to stable and /or unstable fixed point(s). The nature of these solutions are determined by the bandwidth (e) and the stabilizing coefficients (W_ℓ).

We find the stop bandwidths for these two cases by substituting $\cos(\psi_x) = \pm 1$ into eq. (3) and obtaining the following two new equations:

$$F_\pm = \frac{2\pi}{C} e K_x + \sum_{\ell=1} W_\ell K_x^{\frac{\ell}{2}+1} \pm A \qquad (6)$$

For the given initial conditions, four equations can be deduced from Eq. (6) from which the stop bandwidths and the extrem values of Kx are found. These equations are listed below:

$$\begin{aligned} 0 &= F_+(K_{x_0}) - F_+(K_x) \\ 0 &= F_+(K_{x_0}) - F_-(K_x) \\ 0 &= F_-(K_{x_0}) - F_+(K_x) \\ 0 &= F_-(K_{x_0}) - F_-(K_x) \end{aligned} \qquad (7)$$

For $e < \Delta e$ Eqs. (7) can be satisfied for any value of action K, where Δe is the stop bandwidth.

We also note that, Eqs. (8) [5] calculates the necessary distance (δe) between the operating tunes (Qx, Qy) and the resonance line which must be kept to avoid or limit the relative growth of amplitude or beating of a single particle in a given interval $\Lambda = [(Kx/Kxo)^{1/2} - 1]$. Where for a sum resonance

$$\delta e \geqq \frac{\Delta e}{2} \left(1 + \frac{1}{\Lambda} \frac{n_x E_y + n_y E_x}{n_x^2 E_y + n_y^2 E_x}\right) \qquad (8a)$$

and for difference resonance

$$\delta e \geq \frac{\Delta e}{2} \frac{1}{\Lambda} \tag{8b}$$

Nx, Ny are the integers (see eq. (4)) defining a given resonance and Ex and Ey are the emittances of the beam at injection [directly related to Kx and Ky].

In the following sections we discuss our results including the stop bandwidths (defined above) calculated for the alternate lattices using program HARMON (MAD403 [6]).

SECTION III

In this section we consider the 1/4 AGS combined function and 1/4 AGS hybrid lattices shown in Fig. 1 and 2 respectively. Both lattices are very similar with operating tunes at Qx = 4.82, Qy = 4.83 and a periodicity of 12. If the space charge tune shift can be as large as 1 then we must worry about the third order resonances 3Qx = 12 and Qx + 2Qy = 12.

The results of running MAD403 with HARMON are shown in Tables I and II. Table IA gives the orbit parameters for the combined function lattice at the operating tunes, while Table IB gives the orbit parameters at the tunes Qx = 4.01 and Qy = 4.11 near the resonances. The stop bandwidths at the tunes near resonances are given in Table IC. Note e can be as large as about 0.55 which means the tune shift due to the space charge should be less than about 0.73 from the operating tune.

Tables IIA-C gives similar information on the hybrid lattice. It can be seen in Table IIC that the stop bandwidths are larger for the hybrid lattice (Δe = 0.65) than the combined function lattice (Δe = 0.55), but we still can shift the tune as long as the upper limit of tune shift is less than 0.71 (slightly smaller than the above lattice).

SECTION IV

The third lattice we have studied is the 1/3 AGS separated function design with a periodicity of 8 as shown in Fig. 3. If this machine is run at the operating tunes of Qx = 6.82 and Qy = 6.83, then no resonances of up to fourth order are crossed due to space charge tune shifts. The orbit parameters for this case are given in Table IIIA.

If this machine is to run at an alternate set of operating tunes of Qx = 5.82 and Qy = 5.83 then two third order resonances can be crossed at 3Qx = 16 and Qx + 2Qy = 16. The orbit parameters for this case are shown in Table IIIB. Additionally, the orbit parameters at the tunes near resonances are given in Table IIIC. Table IIID gives the stop bandwidths which are of the order of 0.007. These stop bandwidths are small and it is expected that these resonances are passable (although, they may require some tuning out).

SECTION V

The standard AGS - Booster lattice is limited by third order resonances as were the alternate lattices described in the previous sections. If space charge can shift the operating tune of this machine near to the tune of 4 then the third order resonances become noticeable. For tunes near the third order resonances, (for instance, Qx = 4.01 and Qy = 4.11), the orbit parameters are calculated and are given in Table IVA. The stop bandwidths are given in Table IVB which are found to be of the order of 0.076. This suggests that we should limit the space charge tune shifts to within the order of 0.78 before the third order resonance effects becomes important.

VI. CONCLUSION

Due to the space charge tune shifts at injection, resonances that could cause the beam to blow up in an accelerator can be crossed. These resonances in the standard AGS-Booster lattice and its alternates were investigated. Considering the third order resonances, it is found that the stop bandwidths of the 1/4 AGS Combined function and the 1/4 AGS Hybrid lattices have very strong third order resonances limiting the maximum space charge tune shifts that could be handled before there are adverse effects to the beam dynamics. In the standard AGS-Booster, the stop bandwidths for the third order resonances are strong, but we can accommodate space charge tune shifts as large as 0.78, if the fourth order resonances (calculated elsewhere [3,4]) are passable. Finally, the 1/3 AGS separated function lattice at the normal operating tunes does not cross any resonance up to fourth order. However, if this lattice is run at an alternate set of tunes then the third order resonances could be crossed. We found that the stop bandwidths for this resonance are small and these resonances are passable (although, tuning them out may be necessary).

The sixth order resonances are important and will be discused elsewhere, since HARMON is limited to the calculation of fourth order resonances.

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5. M. Donald, D. Schofield, a Users Guide to the Harmon Program, LEP Note 420 (1982); M. Donald private communication (May 1986); using [PARSA1.MAD]MAD403.EXE.

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[In the followng tables COS, SIN and MODULUS (A in Eq.(3)) are the resonance strengths, and DE(S), DQ(S) and DQ20(S) are the stop bandwidths. Where "S" means Systemmatic and "R" means Random].

TABLE IA

```
ALTERNATE AGS-BOOSTER LATTICE WITH CHROMATICITY SEXTUPOLES
AND EDDY CURRENTS
AT OPERATING TUNE (Qx = 4.82, Qy = 4.83)

 BOOSTER LATTICE OF COMBINED FUNCTION ELEMENTS
 DELTA(P)/P =      0.000000

TOTAL LENGTH =  201.780000      NSUP =  12
  QX     =    4.820000          QY     =   4.830000
  QX'    =    0.000000          QY'    =  -0.000003
 ALFA    =    0.509860E-01   GAMMA(TR) =  4.428684
 BETAX         = 1.15267E+01       BETAY =  1.15697E+01
                                    ETAX  =  1.56754E+00
 BETAX(MAX) =   15.591579   BETAY(MAX)= 15.607346
 DX(MAX)    =    2.239726      DY(MAX) = 0.000000

                                    -2
   NORMALIZED STRENGTHS [m     ]
     ID          STRENGTH
------------------------------------
     SFC    -2.76326E-01
     SDC    -1.02324E+00
     SXV1   4.46595E-02
     SXV2   5.58243E-02
     SXV3   7.81541E-02
     SXV4   3.34946E-02
----------------------------------------------------
Q SHIFT EFFECTS [PERTURBATION OF TUNES]

             G22000             DQXDEX         DQX
            --------           --------     ---------
-1.86911E-01  1.60308E+00 -3.73823E-01 -2.55321E-05
              G00220            DQYDEY          DQY
             ---------        -----------    ---------
 2.08373E+01  2.19891E+00  4.16746E+01  2.84637E-03
              G11110            DQXDEY        DQYDEX
             ----------       ----------     ---------
-2.35393E+01  2.93188E+00 -2.35393E+01 -2.35393E+01
                                DQX           DQY
                            -----------   ----------
                           -1.60773E-03 -1.60773E-03
```

TABLE IB

```
ALTERNATE AGS-BOOSTER LATTICE WITH CHROMATICITY SEXTUPOLES
AND EDDY CURRENTS
AT TUNE NEAR RESONANCE (QX = 4.01, QY = 4.11)
```

```
BOOSTER LATTICE OF COMBINED FUNCTION ELEMENTS
DELTA(P)/P =     0.000000

TOTAL LENGTH =  201.780000    NSUP    =  12
   QX =  4.010119                 QY =  4.110112
   QX'=  0.671394                 QY'=  3.951067
ALFA  =  0.689755E-01      GAMMA(TR) =  3.807611
BETAX =  1.04933E+01       BETAY     =  1.04988E+01
                           ETAX      =  2.15115E+00
BETAX(MAX) =  14.547907    BETAY(MAX)= 14.295551
DX(MAX)    =   2.873679    DY(MAX)   =  0.000000

    NORMALIZED STRENGTHS
      ID       STRENGTH
```

ID	STRENGTH
SFC	-2.76326E-01
SDC	-1.02324E+00
SXV1	4.46595E-02
SXV2	5.58243E-02
SXV3	7.81541E-02
SXV4	3.34946E-02

Q SHIFT EFFECTS

	G22000	DQXDEX	DQX
-5.08782E+02	1.34757E+00	-1.01756E+03	-6.94996E-02
	G00220	**DQYDEY**	**DQY**
-1.71354E+02	1.88448E+00	-3.42708E+02	-2.34069E-02
	G11110	**DQXDEY**	**DQYDEX**
-7.64174E+02	2.51264E+00	-7.64174E+02	-7.64174E+02
		DQX	**DQY**
		-5.21931E-02	-5.21931E-02

TABLE IC

ALTERNATE BOOSTER LATTICE WITH [COMBINED FUNCTION ELEMENTS]
WITH CHROMATICITY SEXTUPOLES AND EDDY CURRENTS
DELTA(P)/P= 0.000000 [EX0 =6.8300E-05 EY0 =6.8300E-05]

THIRD ORDER EFFECTS OF SEXTUPOLES [RESONANCE EFFECTS]

3Qx = 12

COSINE	SINE	MODULUS	RANDOM	DE(S)
1.2896E+00	2.7465E-01	1.3185E+00	9.2934E-01	1.9615E-01
DE(R)	DQ(S)	DQ(R)	DQ20(S)	DQ20(R)
1.3825E-01	6.5382E-02	4.6083E-02	1.3512E-01	9.5237E-02

Qx+2Qy=12

COSINE	SINE	MODULUS	RANDOM	DE(S)
3.2830E+00	5.8184E+00	6.6807E+00	4.5129E+00	5.5212E-01
DE(R)	DQ(S)	DQ(R)	DQ20(S)	DQ20(R)
3.7296E-01	2.4691E-01	1.6679E-01	5.1029E-01	3.4471E-01

TABLE IIA

```
ALTERNATE AGS-BOOSTER LATTICE WITH CHROMATICITY SEXTUPOLES
AND EDDY CURRENTS
AT OPERATING TUNE (Qx = 4.82, Qy = 4.83)

------------------------------------------------------------

hybrid BOOSTER LATTICE OF COMBINED FUNCTION ELEMENTS
DELTA(P)/P =  0.000000

TOTAL LENGTH =   201.780000          NSUP     = 12
QX           =     4.820000          QY       =  4.830000
QX'          =     0.000054          QY'      =  0.000031
ALFA         =     0.478141E-01  GAMMA(TR)    =  4.573220
BETAX        =     1.00758E+01   BETAY        =  9.76910E+00
                                 ETAX         =  1.43651E+00
BETAX(MAX)   =    14.058073     BETAY(MAX)    = 13.935099
DX(MAX)      =     2.306863     DY(MAX)       =  0.000000

      NORMALIZED STRENGTHS
         ID      STRENGTH
      --------------------
         SFC   -1.89019E-01
         SDC   -9.73867E-01
         SXV1  8.34574E-02
         SXV2  6.72683E-02
         SXV3  3.76814E-02

Q SHIFT EFFECTS
-------------------
         G22000          DQXDEX         DQX
         -------       -----------  -----------
-5.77230E+00  1.39254E+00 -1.15446E+01 -7.88496E-04
          G00220          DQYDEY          DQY
         --------      ------------  ----------
7.90935E+00  1.81900E+00  1.58187E+01  1.08042E-03
           G11110          DQXDEY        DQYDEX
         ---------     ------------  -----------
-5.80613E+01  2.42533E+00 -5.80613E+01 -5.80613E+01
                                DQX          DQY
                             ----------  -----------
                          -3.96559E-03 -3.96559E-03
```

TABLE IIB

```
ALTERNATE AGS-BOOSTER LATTICE (1/4 AGS) WITH CHROMATICITY
AND EDDY CURRENT SEXTUPOLES
AT TUNES NEAR RESONANCE (Qx = 4.01, Qy = 4.11)

hybrid BOOSTER LATTICE OF COMBINED FUNCTION ELEMENTS
DELTA(P)/P =  0.000000

TOTAL LENGTH =  201.780000       NSUP = 12
QX           =    4.009997       QY   =   4.109997
QX'          =    1.290876       QY' =    3.696270
ALFA         =    0.665890E-01   GAMMA(TR) = 3.875241
BETAX        =  9.90474E+00   BETAY       = 9.63097E+00
                              ETAX        = 2.05177E+00
BETAX(MAX)   =   13.715713    BETAY(MAX)=13.673790
DX(MAX)      =    2.937144       DY(MAX)= 0.000000

     NORMALIZED STRENGTHS
       ID       STRENGTH
-----------------------------
        SFC   -1.89019E-01
        SDC   -9.73867E-01
        SXV1  8.34574E-02
        SXV2  6.72683E-02
        SXV3  3.76814E-02

Q SHIFT EFFECTS
-------------------------------
           G22000           DQXDEX         DQX
           -------          ---------      --------
-8.26976E+02  1.48420E+00 -1.65395E+03 -1.12965E-01
           G00220           DQYDEY         DQY
           -------          ---------      ---------
 -2.45315E+02  1.99024E+00 -4.90630E+02 -3.35100E-02
           G11110            DQXDEY       DQYDEX
           -------           --------     ---------
-1.06011E+03  2.65366E+00 -1.06011E+03 -1.06011E+03
                              DQX          DQY
                             ---------    ----------
                          -7.24052E-02 -7.24052E-02
```

TABLE IIC

ALTERNATE hybrid BOOSTER LATTICE WITH [COMBINED FUNCTION ELEMENTS] WITH CHROMATICITY SEXTUPOLES AND EDDY CURRENTS
DELTA(P)/P= 0.000000 [EX0 =6.8300E-05 EY0 =6.8300E-05]

THIRD ORDER EFFECTS OF SEXTUPOLES [RESONANCE EFFECTS]

3Qx = 12

COSINE	SINE	MODULUS	RANDOM	DE(S)
1.6394E+00	2.8678E-01	1.6643E+00	7.2788E-01	2.4758E-01
DE(R)	DQ(S)	DQ(R)	DQ20(S)	DQ20(R)
1.0828E-01	8.2526E-02	3.6093E-02	1.7055E-01	7.4592E-02

Qx+2Qy=12

COSINE	SINE	MODULUS	RANDOM	DE(S)
5.4062E+00	5.6395E+00	7.8122E+00	4.0555E+00	6.4563E-01
DE(R)	DQ(S)	DQ(R)	DQ20(S)	DQ20(R)
3.3516E-01	2.8874E-01	1.4989E-01	5.9672E-01	3.0977E-01

TABLE IIIA

ALTERNATE AGS-BOOSTER LATTICE (1/3 AGS) WITH CHROMATICITY AND EDDY CURRENT SEXTUPOLES
AT OPERATING TUNES (Qx = 6.82, Qy = 6.83)

BOOSTER LATTICE WITH SEP. FUNCTION ELEMENTS
DELTA(P)/P = 0.000000

TOTAL LENGTH	= 269.040000	NSUP	= 8
QX	= 6.820000	QY	= 6.829999
QX'	= 0.000000	QY'	= 0.000000
ALFA	= 0.221530E-01	GAMMA(TR)	= 6.718681
BETAX	= 3.33250E+00	BETAY	= 1.36827E+01
		ETAX	= 6.38422E-01
BETAX(MAX)	= 14.132757	BETAY(MAX)	= 13.682687
DX(MAX)	= 1.937133	DY(MAX)	= 0.000000

NORMALIZED STRENGTHS

ID	STRENGTH
SXV	6.69892E-02
SFCH	3.71406E-01
SDCH	-9.85768E-01

Q SHIFT EFFECTS

	G22000	DQXDEX	DQX
5.41842E+01	7.57342E-01	1.08368E+02	7.40156E-03
	G00220	DQYDEY	DQY
1.19016E+02	9.16056E-01	2.38032E+02	1.62576E-02
	G11110	DQXDEY	DQYDEX
-7.94214E+01	1.22141E+00	-7.94214E+01	-7.94214E+01
		DQX	DQY
		-5.42448E-03	-5.42448E-03

TABLE IIIB

```
ALTERNATE AGS-BOOSTER LATTICE (1/3 AGS ) WITH CHROMATICITY
AND EDDY CURRENT SEXTUPOLES
AT ALTERNATE  OPERATING TUNES (Qx = 5.82, Qy = 5.83)

BOOSTER LATTICE WITH SEP. FUNCTION ELEMENTS
DELTA(P)/P =  0.000000

TOTAL LENGTH =   269.040000     NSUP = 8
  QX         =     5.819837     QY    =     5.830096
  QX'        =     0.000631     QY'   =      0.000067
 ALFA        =     0.307175E-01 GAMMA(TR) = 5.705678
BETAX        =  4.29045E+00       BETAY = 1.39083E+01
                                   ETAX = 1.02027E+00
BETAX(MAX)    = 14.173987   BETAY(MAX)  = 13.908285
DX(MAX)       =  2.015216      DY(MAX)  =  0.000000

    NORMALIZED STRENGTHS
       ID      STRENGTH
     ------    ---------
       SXV     6.69892E-02
       SFCH    9.83404E-02
       SDCH   -8.31124E-01

Q SHIFT EFFECTS
---------------------------
         G22000              DQXDEX          DQX
        --------            --------       ---------
6.63888E+00  1.03313E+00  1.32778E+01  9.06870E-04
         G00220              DQYDEY          DQY
        --------            --------       ---------
5.07415E+01  1.31499E+00  1.01483E+02  6.93129E-03
         G11110              DQXDEY         DQYDEX
        --------            --------       ---------
-2.41117E+01  1.75332E+00 -2.41117E+01 -2.41117E+01
                               DQX             DQY
                            ---------      ---------
                          -1.64683E-03 -1.64683E-03
```

TABLE IIIC

ALTERNATE AGS-BOOSTER LATTICE (1/3 AGS) WITH CHROMATICITY
AND EDDY CURRENT SEXTUPOLES
AT TUNES NEAR RESONANCE (Qx = 5.34, Qy = 5.35)

BOOSTER LATTICE WITH SEP. FUNCTION ELEMENTS
DELTA(P)/P = 0.000000

TOTAL LENGTH =	269.040000	NSUP =	8
QX =	5.339892	QY =	5.349842
QX' =	1.749702	QY' =	1.046964
ALFA =	0.364175E-01	BETAX(MAX) =	14.497906
BETAX =	4.89019E+00	BETAY =	1.42118E+01
		ETAX =	1.24746E+00
BETAY(MAX) =	14.211846	GAMMA(TR) =	5.240162
DX(MAX) =	2.219571	DY(MAX) =	0.000000

NORMALIZED STRENGTHS

ID	STRENGTH
SXV	6.69892E-02
SFCH	9.83404E-02
SDCH	-8.31124E-01

Q SHIFT EFFECTS

	G22000	DQXDEX	DQX
2.53192E+01	1.63113E+00	5.06385E+01	3.45861E-03

	G11110	DQXDEY	DQYDEX
-1.16873E+02	2.17484E+00	-1.16873E+02	-1.16873E+02

DQX	DQY
-7.98239E-03	-7.98239E-03

TABLE IIID

ALTERNATE BOOSTER LATTICE (1/3 AGS) WITH [SEP. FUNCTION ELEMENTS] CHROMATICITY SEXTUPOLES AND EDDY CURRENTS
DELTA(P)/P= 0.000000 [EX0 =6.8300E-05 EY0 =6.8300E-05]

THIRD ORDER EFFECTS OF SEXTUPOLES [RESONANCE EFFECTS]

3Qx = 16

COSINE	SINE	MODULUS	RANDOM	DE(S)
1.5991E-01	-3.9287E-01	4.2417E-01	7.1560E-01	6.3099E-02
DE(R)	DQ(S)	DQ(R)	DQ20(S)	DQ20(R)
1.0645E-01	2.1033E-02	3.5484E-02	4.3468E-02	7.3333E-02

Qx+2Qy=16

COSINE	SINE	MODULUS	RANDOM	DE(S)
6.5096E-01	-6.5569E-01	9.2395E-01	4.1137E+00	7.6358E-02
DE(R)	DQ(S)	DQ(R)	DQ20(S)	DQ20(R)
3.3997E-01	3.4149E-02	1.5204E-01	7.0574E-02	3.1421E-01

TABLE IVA

```
AGS BOOSTER LATTICE WITH CHROMATICITY SEXTUPOLES
AND EDDY CURRENTS
AT TUNES NEAR RESONANCE (Qx = 4.01, Qy = 4.11)

SEPARATED FUNCTION AGS-BOOSTER LATTICE
DELTA(P)/P =      0.000000

TOTAL LENGTH =   201.780000      NSUP        =  6
QX           =  4.010087         QY          =  4.110047
QX'          =  4.380868         QY'         =  0.364414
ALFA         =  0.631572E-01     GAMMA(TR)   =  3.979134
BETAX(MAX)   = 14.766930         BETAY(MAX)  = 14.019838
BETAX        =  4.62840E+00      BETAY       =  1.39299E+01
                                 ETAX        =  1.31580E+00
DX(MAX)      =  3.169083         DY(MAX)     =  0.000000

      NORMALIZED STRENGTHS
         ID       STRENGTH
      ----------------------
         SXF    5.90305E-02
         SXD   -8.04138E-01
         SXV    1.35000E-01

Q SHIFT EFFECTS
-------------------
              G22000                   DQXDEX          DQX
              -------                  ------          ---
  -4.56809E+00   6.12823E-16  -9.13617E+00  -6.24001E-04
              G00220                   DQYDEY          DQY
              -------                  ------          ---
   2.80864E+01   2.85772E-15   5.61727E+01   3.83660E-03
              G11110                   DQXDEY         DQYDEX
              -------                  ------         ------
  -2.14197E+01   1.42251E-14  -2.14197E+01  -2.14197E+01
                                         DQX            DQY
                                         ---            ---
                              -1.46296E-03  -1.46296E-03
```

TABLE IVB

STANDARD AGS - BOOSTER WITH CHROMATICITY SEXTUPOLES AND EDDY CURRENTS
DELTA(P)/P= 0.000000 [EX0 =6.8300E-05 EY0 =6.8300E-05]

THIRD ORDER EFFECTS OF SEXTUPOLES [RESONANCE EFFECTS]

3Qx = 12

COSINE	SINE	MODULUS	RANDOM	DE(S)
1.3100E-01	-7.6377E-02	1.5164E-01	6.9477E-01	2.2558E-02

DE(R)	DQ(S)	DQ(R)	DQ20(S)	DQ20(R)
1.0335E-01	7.5193E-03	3.4451E-02	1.5540E-02	7.1199E-02

Qx + 2Qy = 12

COSINE	SINE	MODULUS	RANDOM	DE(S)
9.2324E-01	1.0306E-02	9.2329E-01	3.5080E+00	7.6304E-02

DE(R)	DQ(S)	DQ(R)	DQ20(S)	DQ20(R)
2.8992E-01	3.4124E-02	1.2965E-01	7.0524E-02	2.6795E-01

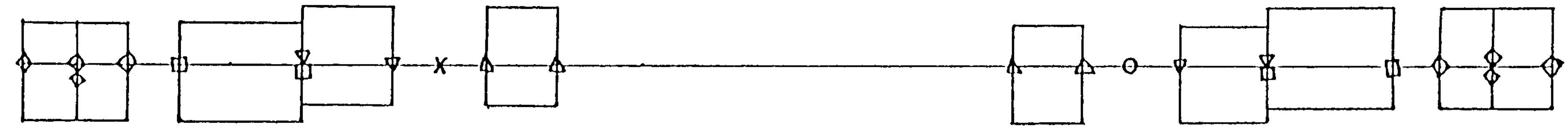

Fig. 1 1/4 AGS Combined function (Length - 16.815m)

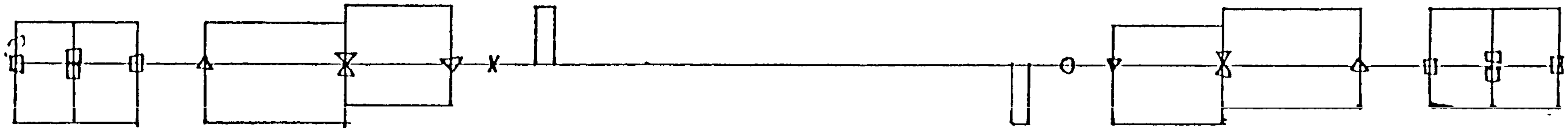

Fig. 2 1/4 AGS Hybrid (Length - 16.815m)

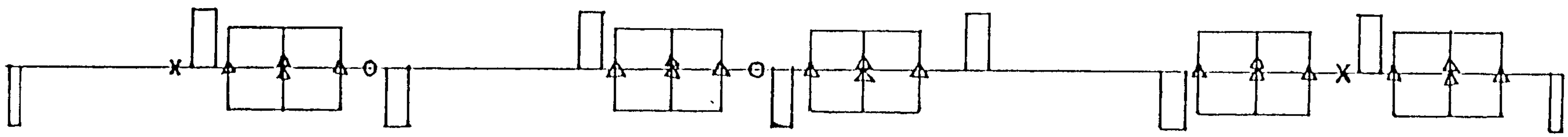

Fig. 3 1/3 AGS Separated function (Length - 33.63m)

[x - SFC, o - SDC, △- SXV1, ▽- SXV2, □- SXV3, ◊- SXV4 for Figs. 1 and 2]
[x - SFCH, o - SDCH, △ - SXV for Fig. 3]

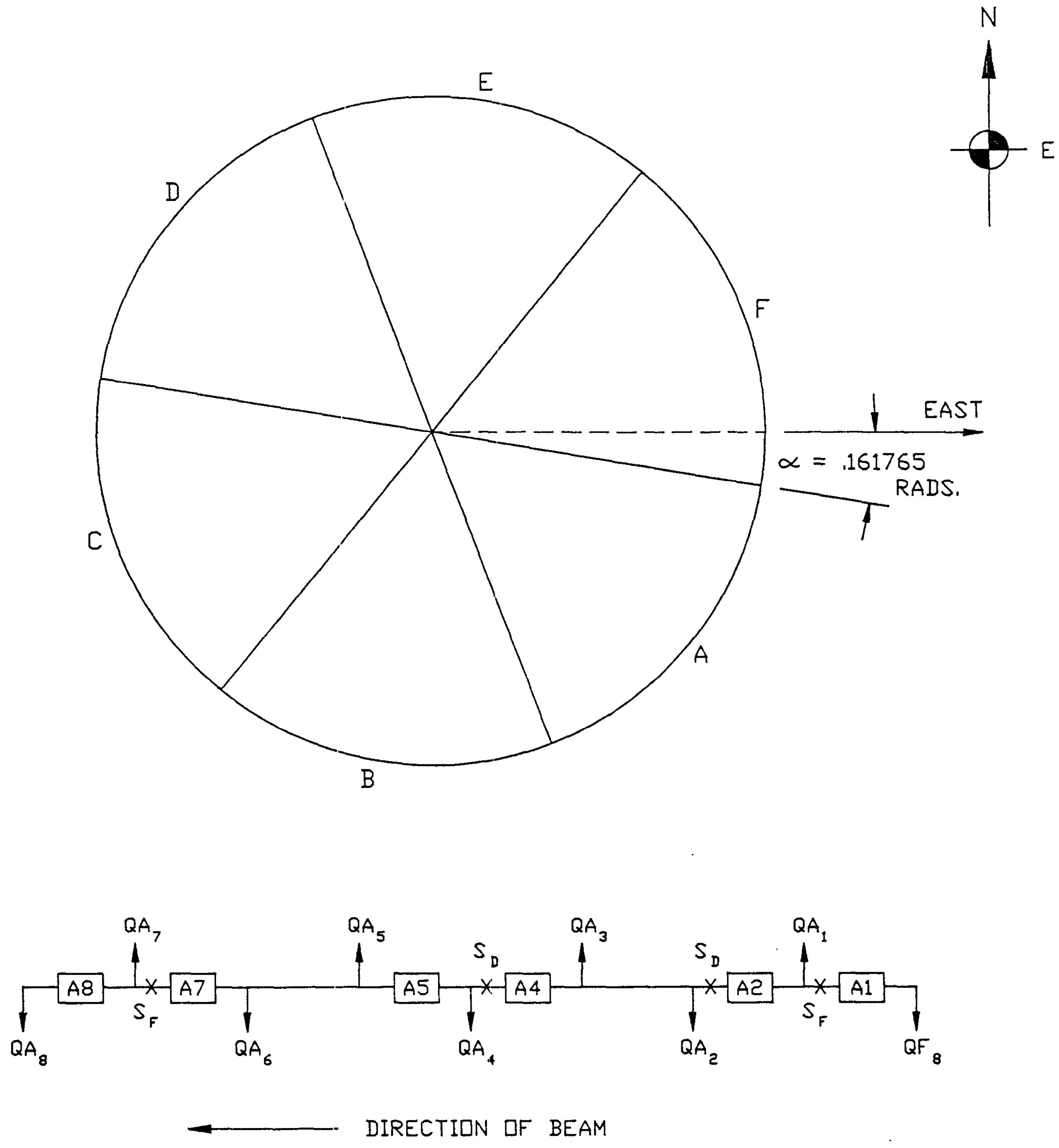

Fig. 4a Standard AGS - Booster

↑ = FOCUSING QUADRUPOLE

↓ = DEFOCUSING QUADRUPOLE

□ = BENDING MAGNET (DIPOLE)

X = SEXTUPOLE

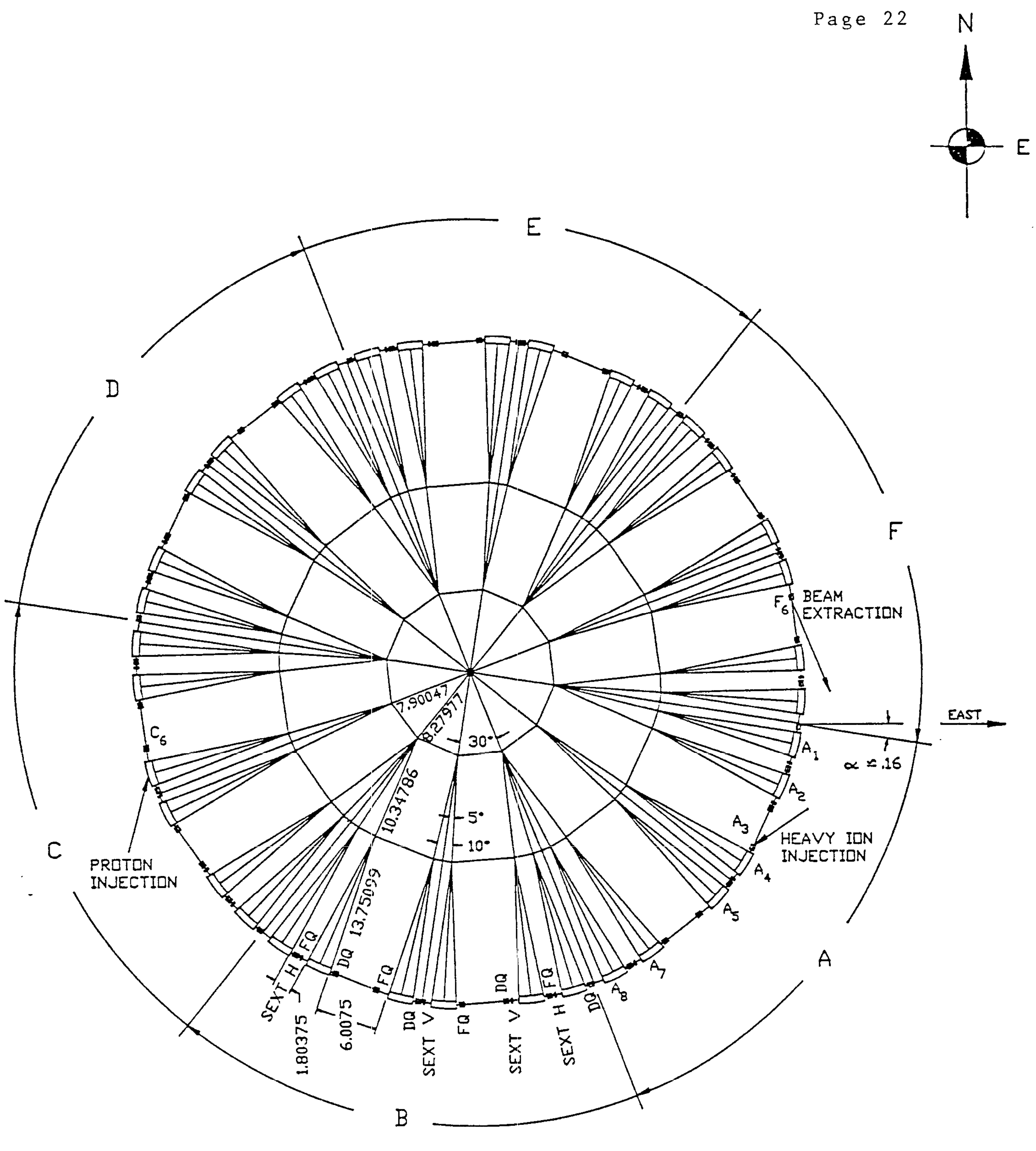

Fig. 4b The Standard AGS - Booster Lattice

NOTE: ALL DIMENSIONS ARE IN METERS