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Analysis of resonances in the AGS Booster

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ANALYSIS OF RESONANCES IN THE AGS BOOSTER

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ABSTRACT

THE FOURTH ORDER STRUCTURE RESONANCES OF THE BOOSTER LATTICE ARE INVESTIGATED. THESE RESONANCES ARE CROSSED AT INJECTION BECAUSE OF THE SPACE CHARGE TUNE SHIFT. THE STOP BANDWIDTHS WERE OBTAINED USING HARMON (THROUGH PROGRAM MAD403).

I. INTRODUCTION

We have studied the nonlinear effects on the Dynamical systems with the emphasis on nonlinear resonances. Some of our results were incorporated into a program "NONLIN" that we have used to study (specifically the fourth order) resonances of the AGS - Booster [1]. In this paper we present some of our findings for the booster [2,3] using the alternate program (MAD403) Harmon [4]. This program is based on "finding the adverse effects of a particular quadrupole - sextupole configuration and then adjusting the sextupole strengths to minimize these effects". The functions to be minimized are chromatic effects (variation of particle motion with respect to the variation in particle momentums) and - non chromatic effects (due to presence of nonlinear elements (chromaticity correction sextupoles).

SECTION II

The fourth order structure resonances of the booster lattice are investigated. These resonances are crossed at injection because of space charge tune shift. Calculations of space charge shows that we can expect a tune shift as large as 1. Since the booster has a periodicity of 6 and the operating tunes of $Q_x = 4.82$ and $Q_y = 4.83$ then at least three (possibly four) fourth order resonances may be crossed.

The fourth order resonances investigated are:

$$4\,Q_x = 18 \qquad (1a)$$

$$2\,Q_x + 2\,Q_y = 18 \qquad (1b)$$

$$4\,Q_y = 18 \qquad (1c)$$

$$2\,Q_x - 2\,Q_y = 0. \qquad (1d)$$

In this note, the stop bandwidths were obtained using HARMON (through MAD4.03) [4]. These stop bandwidth calculations assume that we are close to the resonance in question but far from all the others. This doesn't appear likely in this case. This problem as well as the results of our studies of the resonances in the alternate AGS - booster lattices are given elsewhere [1,5].

The method used to calculate stop bandwidths in HARMON are given in detail by Guignard [6]. The perturbing part of the hamiltonian near a given resonance can be expressed as:

$$G = f(r1,r2) + g(r1,r2)\cos\psi \qquad (2)$$

where r1 and r2 are the actions (proportional to the square root of the emittance) and conjugate phase ψ. As long as the other resonances do not contribute to the dynamics then the Eq.(2) is an approximate invariant. The stop bandwidths are the limit at which the "emittances" r1 and r2 cannot grow without bounds. These results are given in the tables that follow.

The lattice includes the eddy current sextupoles and chromaticity correcting sextupoles [2] (for the lattice at the operating tunes Qx = 4.82 and Qy = 4.83). The resonances were calculated for the lattice tuned to the tunes of Qx = 4.501 and Qy = 4.511 close to the four resonances being investigated.

The lattice parameters are given in Table I. Tables II through IV gives the resonance strengths and stop bandwidths as calculated from HARMON. The stop bandwidths are of the order of .002 for the three resonances given by Eqs. (1a-c). In all, we may cross six resonances. Three on the way down as the tune is shifted due to the space charge and three on the return as the effect of the space charge diminishes and the tune returns back into its operating values. Since the strength is small and we expect to cross each resonance quickly, then each resonance would lead to a small growth in the emittance. However, the accumulative effect of crossing six resonances should be considered [1].

REFERENCES:

1. Z. Parsa, S. Tepikian and E. Courant, Fourth Order Resonances in the AGS - Booster Lattice, Booster Tech. Note No.

2. Booster Lattice with Enlarged Q5 and 1,2,4,7 Sextupole Configuration. Booster Tech. Note No.26, E. Courant and Z. Parsa, (April 21,1986).

3. Booster Parameters with Enlarged Q5, Booster Tech. Note No. 25, Z. Parsa, (April 17, 1986).

4. 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.

5. Z. Parsa, S. Tepikian, Alternate AGS - Booster Lattices, Booster Tech. Note No. 32 (May 1986)

Table I

AGS BOOSTER LATTICE WITH CHROMATICITY SEXTUPOLES
AND EDDY CURRENTS
PARAMETERS AT START OF LATTICE

TOTAL LENGTH = 201.780000 NSUP = 6

QX = 4.501049 QY = 4.5109
QX'= 1.699386 QY'= 0.010820

ALFA = 0.494546E-01 GAMMA(TR) = 4.496729
BETAX = 3.98217E+00 BETAY = 1.37381E+01
ETAX = 8.51585E-01
BETAX(MAX) = 14.176944 BETAY(MAX) = 13.812846
DX(MAX) = 2.890904 DY(MAX)= 0.000000

NORMALIZED STRENGTHS [m^{-2}]

ID	STRENGTH
SFCH	5.90305E-02
SDCH	-8.04138E-01
SFED	1.35000E-01

Q SHIFT EFFECTS [PERTURBATION OF TUNES]

G22000	DQXDEX	DQX
3.76592E+00	-8.91030E-17	7.53183E+00	5.14424E-04

G00220	DQYDEY	DQY
3.74536E+01	3.32694E-16	7.49072E+01	5.11616E-03

G11110	DQXDEY	DQYDEX
-5.44314E+00	1.24852E-15	-5.44314E+00	-5.44314E+00

DQX	DQY
-3.71766E-04	-3.71766E-04

**

[IN THE FOLLOWNG TABLES COS, SIN, DE, DQ, DQ(20) ARE
THE RESONANCE STRENGTHS, AND DE = STOPBAND WIDTH.]

Table II

AGS BOOSTER LATTICE WITH CHROMATICITY SEXTUPOLES
AND EDDY CURRENTS | [EX0 = 6.8300E-05 EY0 = 6.8300E-05]

RESONANCE EFFECTS, DELTA(P)/P = 0.000000
FOURTH ORDER EFFECTS OF SEXTUPOLES

COS	SIN	DE	DQ	DQ(20)
4Qx = 18				
1.3792E+00	-1.0106E+00	1.8685E-03	1.1277E-03	1.6315E-03
4Qy = 18				
3.4649E+00	-8.1212E-01	3.8891E-03	2.3473E-03	3.3959E-03
2Qx+2Qy=18				
1.1083E+01	-2.7383E+00	6.2380E-03	5.3245E-03	7.7031E-03
2Qx-2Qy= 0				
-3.7045E+01	3.0767E+00	3.7173E+01		

FOURIER ANALYSIS. ORDER OF RESONANCE

4Qx = 18

COSINE	SINE	MODULUS	RANDOM	DE(S)
-1.4047E-01	7.4337E-02	1.5893E-01	2.1098E-01	4.1929E-04
DE(R)	DQ(S)	DQ(R)	DQ20(S)	DQ20(R)
5.5663E-04	1.0482E-04	1.3916E-04	1.5165E-04	2.0132E-04

2Qx+2Qy=18

COSINE	SINE	MODULUS	RANDOM	DE(S)
8.6603E-01	1.0192E+00	1.3375E+00	1.7686E+00	1.7643E-03
DE(R)	DQ(S)	DQ(R)	DQ20(S)	DQ20(R)
2.3330E-03	6.2378E-04	8.2483E-04	9.0245E-04	1.1933E-03

4Qy = 18

COSINE	SINE	MODULUS	RANDOM	DE(S)
5.9395E-01	5.4899E-01	8.0881E-01	7.1490E-01	2.1338E-03
DE(R)	DQ(S)	DQ(R)	DQ20(S)	DQ20(R)
1.8861E-03	5.3346E-04	4.7152E-04	7.7177E-04	6.8217E-04

2Qx-2Qy= 0

COSINE	SINE	MODULUS	RANDOM
1.8614E-01	0.0000E+00	1.8614E-01	1.7686E+00

Table III

AGS BOOSTER LATTICE WITH CHROMATICITY SEXTUPOLES AND EDDY CURRENTS | [EX0 = 1.0000E-04, EY0 = 5.0000E-05]

RESONANCE EFFECTS, DELTA(P)/P = 0.000000

COS	SIN	DE	DQ	DQ(20)
4Qx = 18				
1.3792E+00	-1.0106E+00	2.7357E-03	1.6511E-03	2.3887E-03
4Qy = 18				
3.4649E+00	-8.1212E-01	2.8471E-03	1.7184E-03	2.4860E-03
2Qx+2Qy=18				
1.1083E+01	-2.7383E+00	6.8500E-03	5.8468E-03	8.4588E-03
2Qx-2Qy=0				
-3.7045E+01	3.0767E+00	3.7173E+01		

FOURIER ANALYSIS. ORDER OF RESONANCE

4Qx = 18.

COSINE	SINE	MODULUS	RANDOM	DE(S)
-1.4047E-01	7.4337E-02	1.5893E-01	2.1098E-01	6.1389E-04
DE(R)	DQ(S)	DQ(R)	DQ20(S)	DQ20(R)
8.1498E-04	1.5347E-04	2.0374E-04	2.2203E-04	2.9476E-04

2Qx+2Qy=18.

COSINE	SINE	MODULUS	RANDOM	DE(S)
8.6603E-01	1.0192E+00	1.3375E+00	1.7686E+00	1.9374E-03
DE(R)	DQ(S)	DQ(R)	DQ20(S)	DQ20(R)
2.5618E-03	6.8497E-04	9.0574E-04	9.9097E-04	1.3104E-03

4Qy = 18.

COSINE	SINE	MODULUS	RANDOM	DE(S)
5.9395E-01	5.4899E-01	8.0881E-01	7.1490E-01	1.5621E-03
DE(R)	DQ(S)	DQ(R)	DQ20(S)	DQ20(R)
1.3807E-03	3.9053E-04	3.4519E-04	5.6499E-04	4.9939E-04

2Qx-2Qy=0.

COSINE	SINE	MODULUS	RANDOM
1.8614E-01	0.0000E+00	1.8614E-01	1.7686E+00

Table IV

AGS BOOSTER LATTICE WITH CHROMATICITY SEXTUPOLES AND EDDY CURRENTS | [EX0 = 5.0000E-05 EY0 = 5.0000E-05]

RESONANCE EFFECTS, DELTA(P)/P = 0.000000

COS	SIN	DE	DQ	DQ(20)
4Qx = 18				
1.3792E+00	-1.0106E+00	1.3678E-03	8.2557E-04	1.1944E-03
4Qy = 18				
3.4649E+00	-8.1212E-01	2.8471E-03	1.7184E-03	2.4860E-03
2Qx+2Qy=18				
1.1083E+01	-2.7383E+00	4.5666E-03	3.8979E-03	5.6392E-03
2Qx-2Qy= 0				
-3.7045E+01	3.0767E+00	3.7173E+01		

FOURIER ANALYSIS. ORDER OF RESONANCE

4Qx = 18

COSINE	SINE	MODULUS	RANDOM	DE(S)
-1.4047E-01	7.4337E-02	1.5893E-01	2.1098E-01	3.0694E-04
DE(R)	DQ(S)	DQ(R)	DQ20(S)	DQ20(R)
4.0749E-04	7.6736E-05	1.0187E-04	1.1102E-04	1.4738E-04

2Qx+2Qy=18

COSINE	SINE	MODULUS	RANDOM	DE(S)
8.6603E-01	1.0192E+00	1.3375E+00	1.7686E+00	1.2916E-03
DE(R)	DQ(S)	DQ(R)	DQ20(S)	DQ20(R)
1.7079E-03	4.5665E-04	6.0383E-04	6.6065E-04	8.7358E-04

4Qy = 18

COSINE	SINE	MODULUS	RANDOM	DE(S)
5.9395E-01	5.4899E-01	8.0881E-01	7.1490E-01	1.5621E-03
DE(R)	DQ(S)	DQ(R)	DQ20(S)	DQ20(R)
1.3807E-03	3.9053E-04	3.4519E-04	5.6499E-04	4.9939E-04

2Qx-2Qy= 0

COSINE	SINE	MODULUS	RANDOM
1.8614E-01	0.0000E+00	1.8614E-01	1.7686E+00

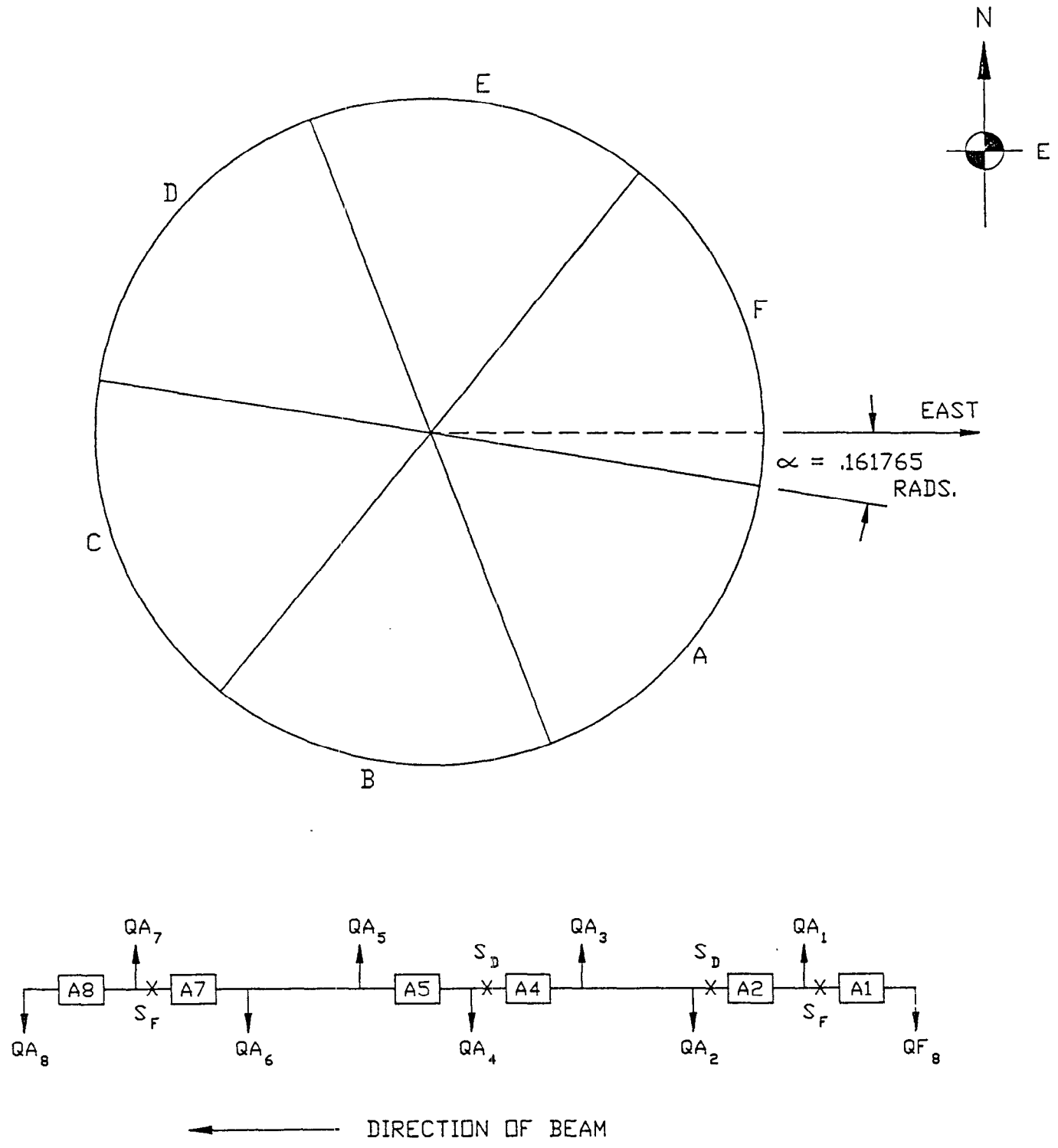

Fig. 1a Standard AGS - Booster

↑ = FOCUSING QUADRUPOLE

↓ = DEFOCUSING QUADRUPOLE

□ = BENDING MAGNET (DIPOLE)

X = SEXTUPOLE

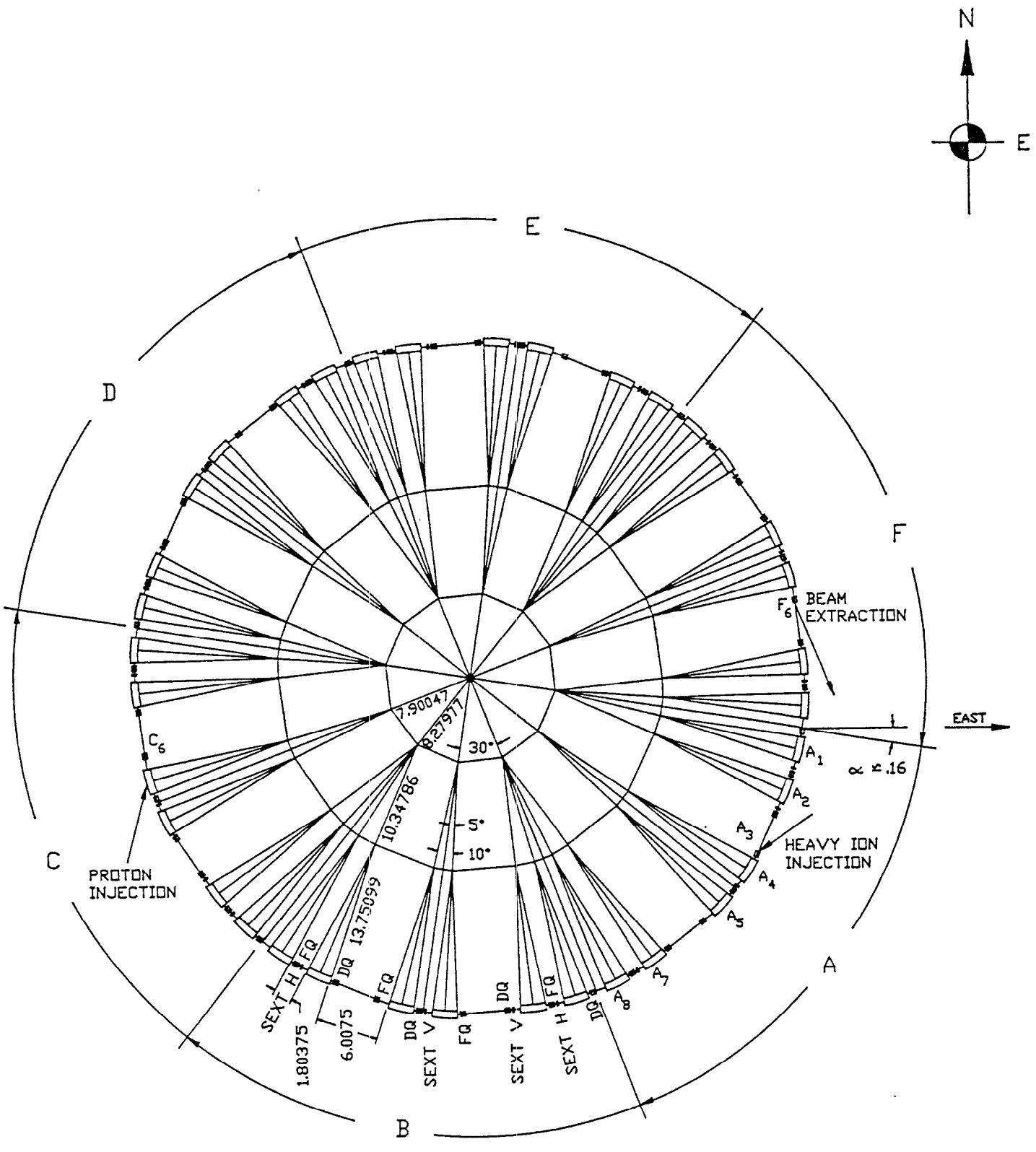

Fig. 1b AGS - BOOSTER LATTICE

0 5
METERS

NOTE: ALL DIMENSIONS ARE IN METERS