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MAGNETIC FIELD DESIGN OF THE ACCUMULATOR MULTIPOLE MAGNET

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INTRODUCTION

A multipole magnet using the FFAG graded coil technique[1] has been designed with the aid of the two dimensional magnet modelling code Poisson[2]. Rapid design interaction in problem formulation has been achieved with a new finite element mesh generator[3] in which mesh densities can be manipulated to overcome difficulties in mesh topologies when spanning the grid over the problem domain.

In the graded coil method, slots are provided in the poleface for windings whose number is chosen to give a magnetic potential such that its continuation into the working space (beam aperture) provides the desired multipole field. Two sets of windings have been studied here, to produce both a sextupole and, independently, an octupole field within a working area with a horizontal to vertical aspect ratio of 4.3/0.9. Both fields are required to provide sufficient degrees of freedom for tuning the betatron frequency dependence of the accumulator, resulting from the large momentum spread of the stored beam. Table I below summarizes the coil arrays used in the modelling studies for the two magnet excitation modes. Two variations of steel surface geometries are discussed, one yielding a 10% larger vertical opening than the other.

Table I. Sextupole/Octupole Parameters

Sextupole Coil Arrays			Octupole Coil Arrays		
Conductor	Turns	Modelled AmpxTurns	Conductor	Turns	Modelled AmpxTurns
SY	15	6345	OY	40	600
SA	2	-846	OA	12	-180
SB	4	-1692	OB	14	-210
SC	4	-1692	OC	9	-135
SD	3	-1269	OD	5	-75
SE	2	-846	OE	1	-15
SF	1	-423	OF	1	+15

CONNECTIONS:

1. Sextupole: Packages SA, SB, SC, SD, SE are returned by SY package. SF is returned by a Twin Conductor in the second quadrant.
2. Octupole: Packages OA, OB, OC, OD are returned by OY. Package OE is returned by OF.

FIELD QUALITY SPECIFICATION

A memo by S. Holmes[4] indicates that in the region allotted to this correction element the accumulator beam occupies an area of +/-4.38 inches horizontally by +/-0.9 inches vertically, during the various phases of injection, cooling and stacking. Field quality is defined here in terms of the allowable deviation of the field gradient from the nominal sextupole/ octupole components, corresponding to an associated betatron tune spread.

The target tolerance on the field gradient used here was[4]

$$\text{Delta}(DB/DX) = +/-2.50 \quad \text{Gauss/inch.}$$

within the good field aperture. While this tolerance is required for the stored beam, at the outer edges used by injected/extracted beams, this tolerance can be relaxed somewhat.

The two excitations produced for these yoke/coil configurations can be described by their harmonic content. Assuming no construction errors the allowed harmonics are defined by the coil symmetries about the X/Y axes. Thus: for the array used to produce a sextupole field:

$$B_y = k_1+k_3(x^2-y^2)+k_5(x^4-6x^2y^2+y^4) \text{ ....etc}$$

for the array used to produce an octupole field:

$$B_y = k_2.x+k_4(x^3-3xy^2)+k_6(x^5-10x^3y^2+5xy^4)+ \text{ .etc.}$$

In each case, the first term is an undesirable subharmonic, while the second terms are the dominant harmonic sought for. The higher order terms (3rd, 4th etc.) can be minimized; the harmonics associated with the tooth periodicity while not significant near the median plane, determine the useful aperture off the median plane. The dipole subharmonic produced in the sextupole excitation arises from the non ideal net current difference, resulting from integer ratios in the coil distributions. This is typically 30-40 gauss at the nominal excitation. The quadrupole subharmonic possible in the octupole excitation has been virtually eliminated by the "OE" conductor, and a reduction of the OY package to 40 turns.

Good field analysis keys on the vertical field gradient for this application. From the derived expressions for DBY/DX, it is evident that departures from a straight line (sextupole) or a parabola (octupole) monitor the quantity of the higher order harmonics, for the corresponding coil arrays, since:

$$dB_y/dx = 2k_3.x \text{ for the sextupole harmonic}$$

and $$dB_y/dx = 3k_4(x^2-y^2) \text{ for the octupole.}$$

The desired values for the multipole strengths[4] are:

$$k_3 = 50.0 \text{ gauss/in.}^2$$

$$k_4 = 0.75 \text{ gauss/in.}^3$$

SEXTUPOLE DESIGN

The coil and yoke configuration is shown in Figure I for the sextupole excitation. Only 1/4 of the magnet is modelled because of the available symmetry.

Typical flux lines are shown with the appearance of the sextupole fluxline topology clearly visible near the origin.

A plot of the gradient of vertical flux density (DBY/DX) along the median plane, and 0.9 inches above the median plane is shown in Figure II and Figure III corresponding to two steel tip designs. For a pure sextupole, this should be a straight line passing through the origin. The high frequency oscillation of the field gradient off the median plane is caused by the proximity of the steel tips used to define the equipotential surfaces arising from the graded coil packages. Model IV attains the field gradient tolerance along the median plane to x = 4.3 inches, and provides good quality off the median plane (DY = 0.9 inch) up to x = 3.5 inches.

Sextupole excitation summary: (Refer to Figure IV)

Tip Edge Heights					*Field Compn.		Slope Deviation (gauss/in.)	
	BF	A1	A2	G	k3	k1		
	In.	In.	In.	In.	G/In2	Gauss	At x=4.0 inches	
					Sext.	Dipole	Y=0	Y=0.9 in.
Model								
II	1.9	1.70	1.60	1.55	54.2	-49.1	-3.0	+19.0
IV	2.09	1.87	1.76	1.55	49.4	-31.7	+0.5	+10.0

OCTUPOLE DESIGN

Figure V shows the octupole coil distribution and the predicted flux pattern using the same yoke design as the sextupole. The off median plane field gradient deviations for the octupole case are small, typically +/- 1.5 gauss/inch, well within the tolerance band.

Figure VI illustrates the predicted vertical field gradient (DBY/DX) variation horizontally at 0.9 inches above the median plane. The off median plane function should parallel the slope function on the median plane. Some high frequency oscillation can be seen for the off median plane case.

Octupole excitation summary:

Model	k4(G/In^3) (Octupole)	k2(G/in) (Quadrupole)
II	0.83	0.5
IV	0.74	0.16

CONCLUSION

Design study of the combined sextupole/octupole graded coil magnet for the accumulator using the "Poisson" modelling code predict sufficient field purity is available in the two geometries studied. Steel modelled was a low carbon steel, similar to MR steel. However, modelling with infinite permeability implied no appreciable saturation effects, at the nominal current.

Tolerance on pole tip location and coil placement, indicated that 10 mil tip tolerances and 0.5 inch coil motion within the slots was allowable.

Note that no end field contributions (3D) are estimated here.

REFERENCES

1. D. Kerst, et al., Rev. Sci. Int. Vol. 31, No. 10, p. 1076

2. CHR. Iselin, Program "Poiscr", CERN Report T604, 1982

3. L. Oleksiuk, "Fermesh-An Intelligent Mesh Generator for Finite Element Methods", (In preparation)

4. S. Holmes, private communication

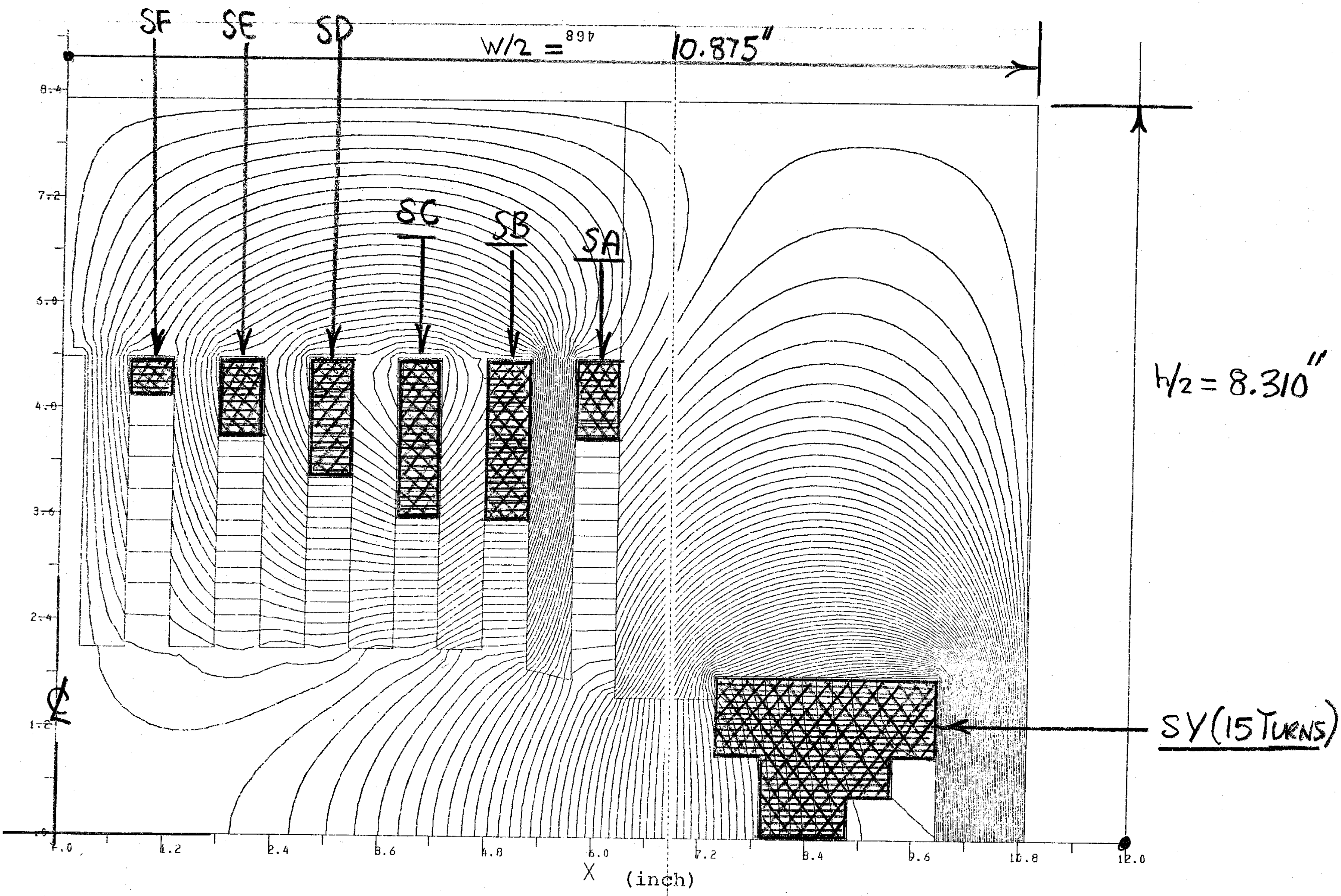


FIGURE I Sextupole coil array and resulting flux distribution.

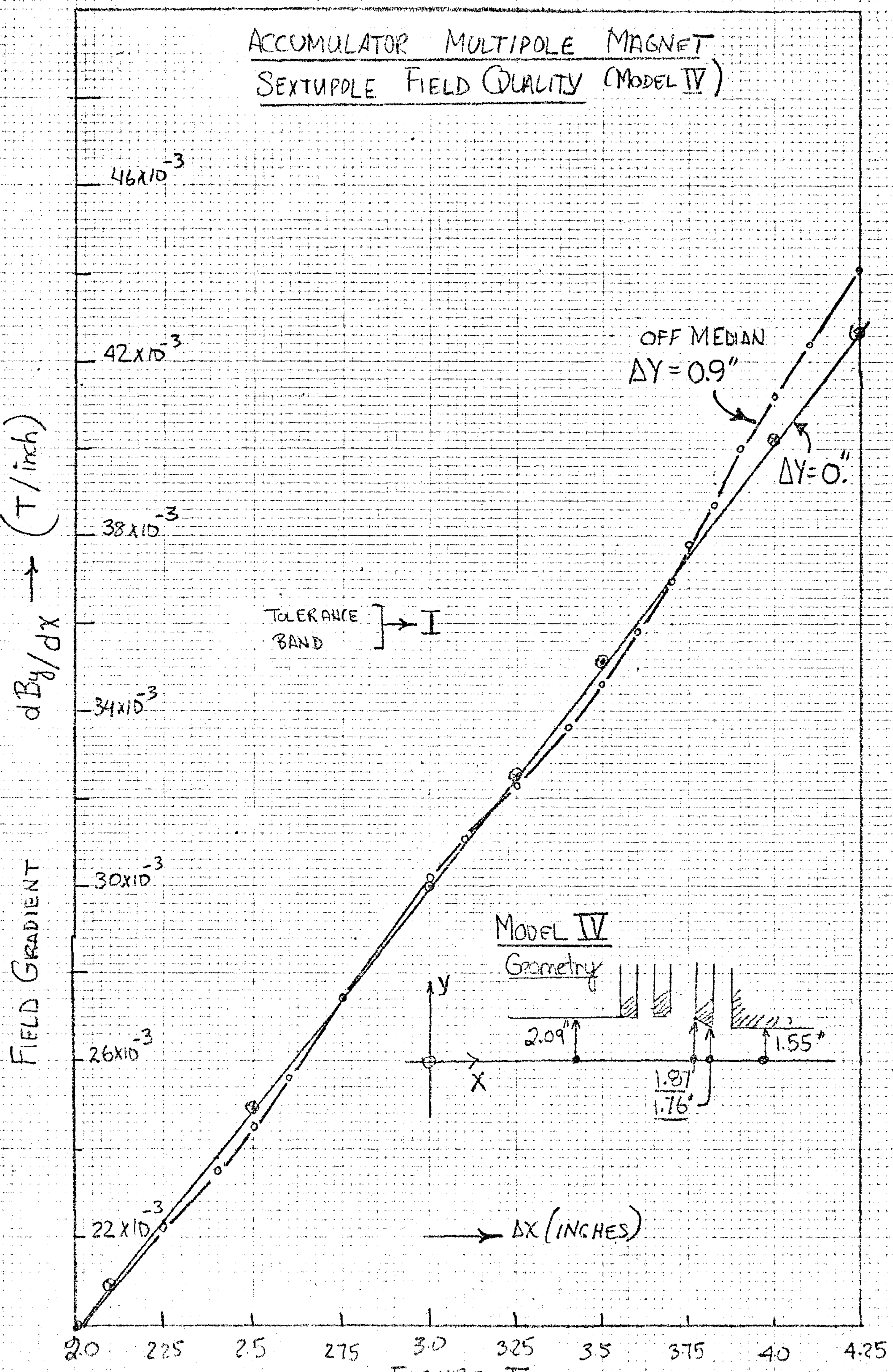
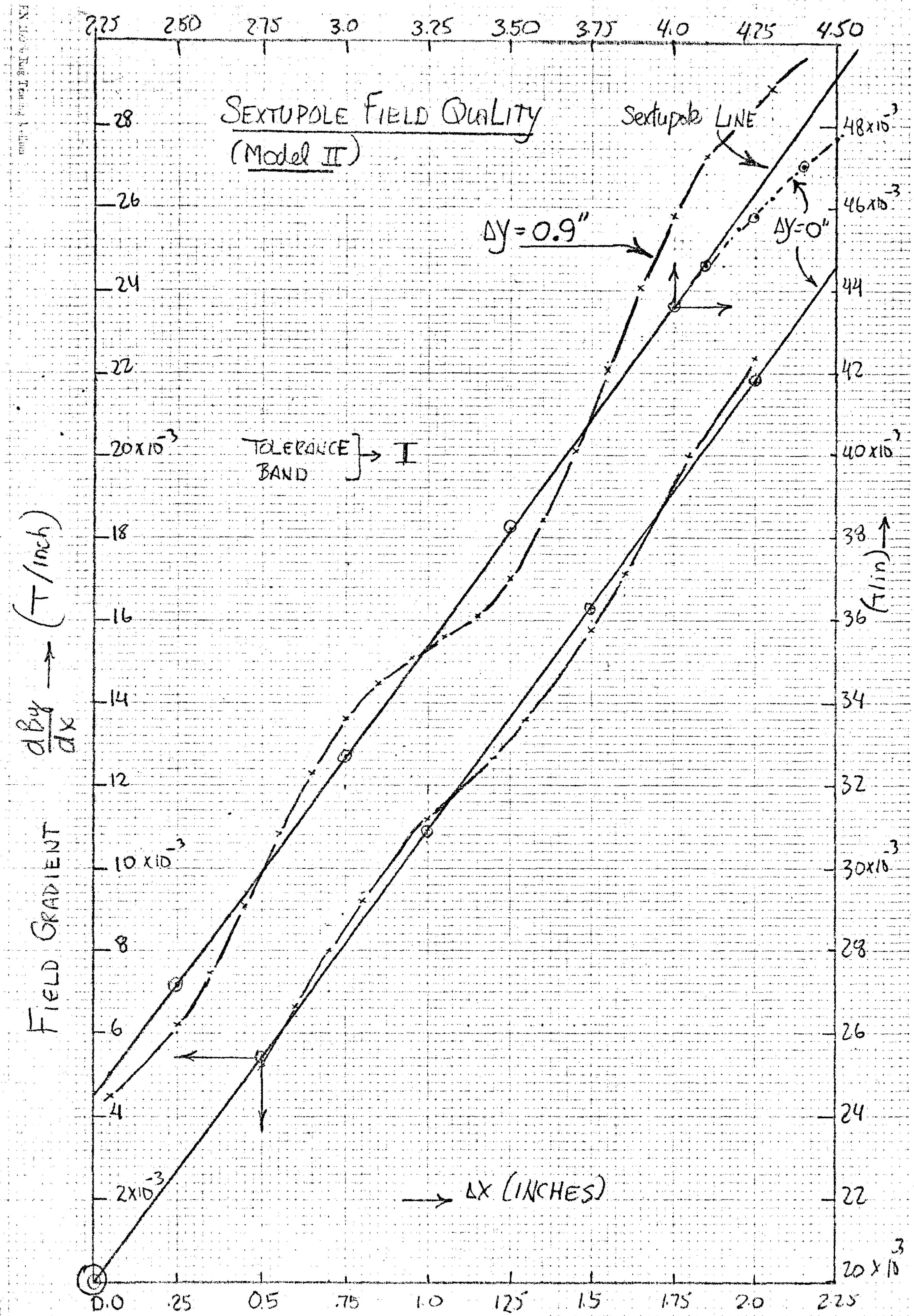

ACCUMULATOR MULTIPOLE MAGNET
SEXTUPOLE FIELD QUALITY (MODEL IV)
46x10^-3
42x10^-3
38x10^-3
34x10^-3
30x10^-3
26x10^-3
22x10^-3
FIELD GRADIENT dBy/dx → (T/inch)
OFF MEDIAN
ΔY=0.9"
ΔY=0"
TOLERANCE BAND → I
MODEL IV
Geometry
y
x
2.09"
1.97"
1.76"
1.55"
→ ΔX (INCHES)
2.0
2.25
2.5
2.75
3.0
3.25
3.5
3.75
4.0
4.25

FIGURE II



SEXTUPOLE FIELD QUALITY
(Model II)
Sextupole LINE
ΔY = 0.9"
ΔY = 0"
TOLERANCE BAND → I
FIELD GRADIENT dBy/dx → (T/inch)
(T/in) ↑
→ ΔX (INCHES)
2.25 2.50 2.75 3.0 3.25 3.50 3.75 4.0 4.25 4.50
0.0 .25 0.5 .75 1.0 1.25 1.5 1.75 2.0 2.25
2x10^-3 4 6 8 10x10^-3 12 14 16 18 20x10^-3 22 24 26 28
20x10^-3 22 24 26 28 30x10^-3 32 34 36 38 40x10^-3 42 44 46x10^-3 48x10^-3

FIGURE III

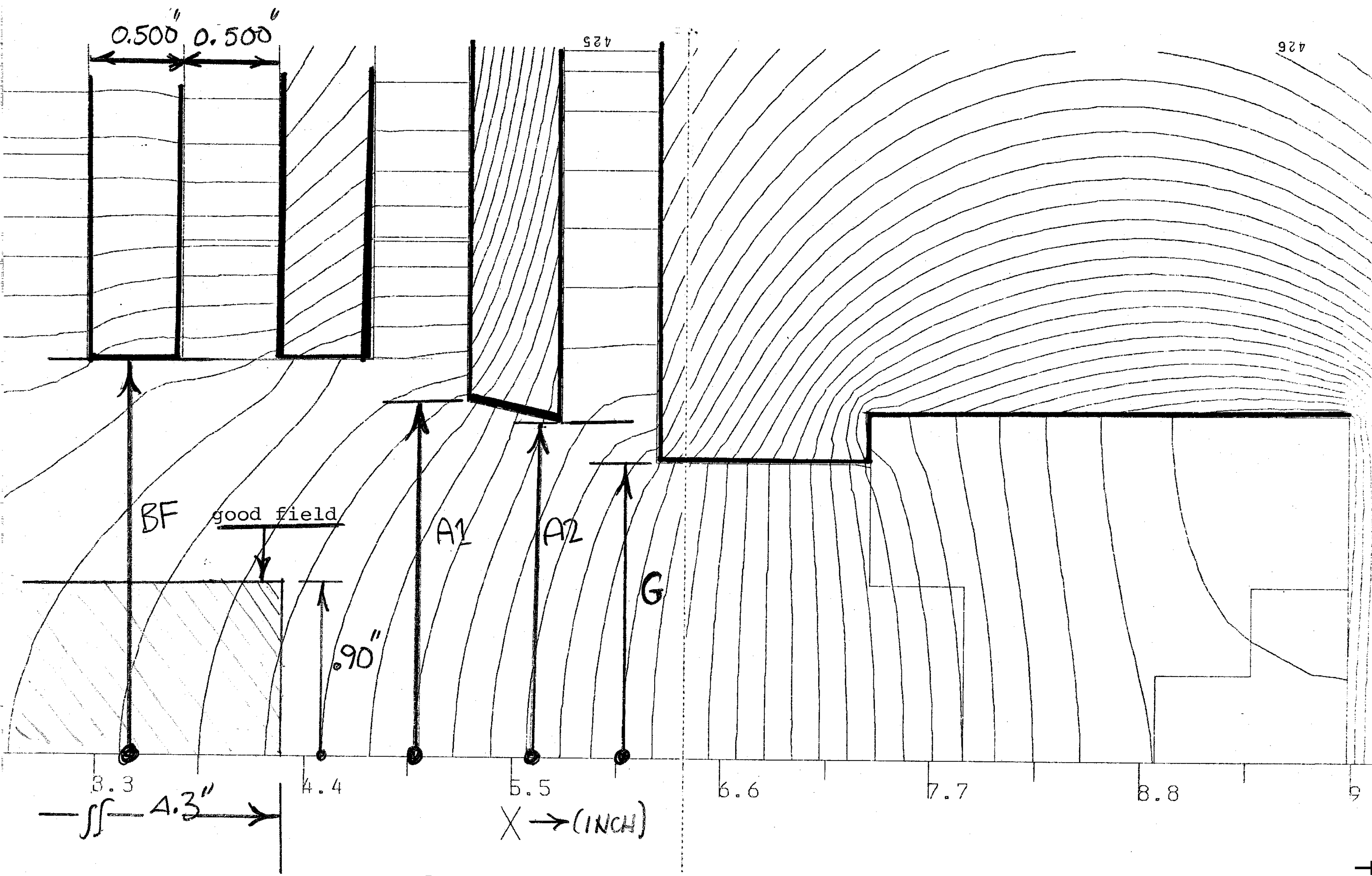


FIGURE IV Good field region and defining steel boundaries

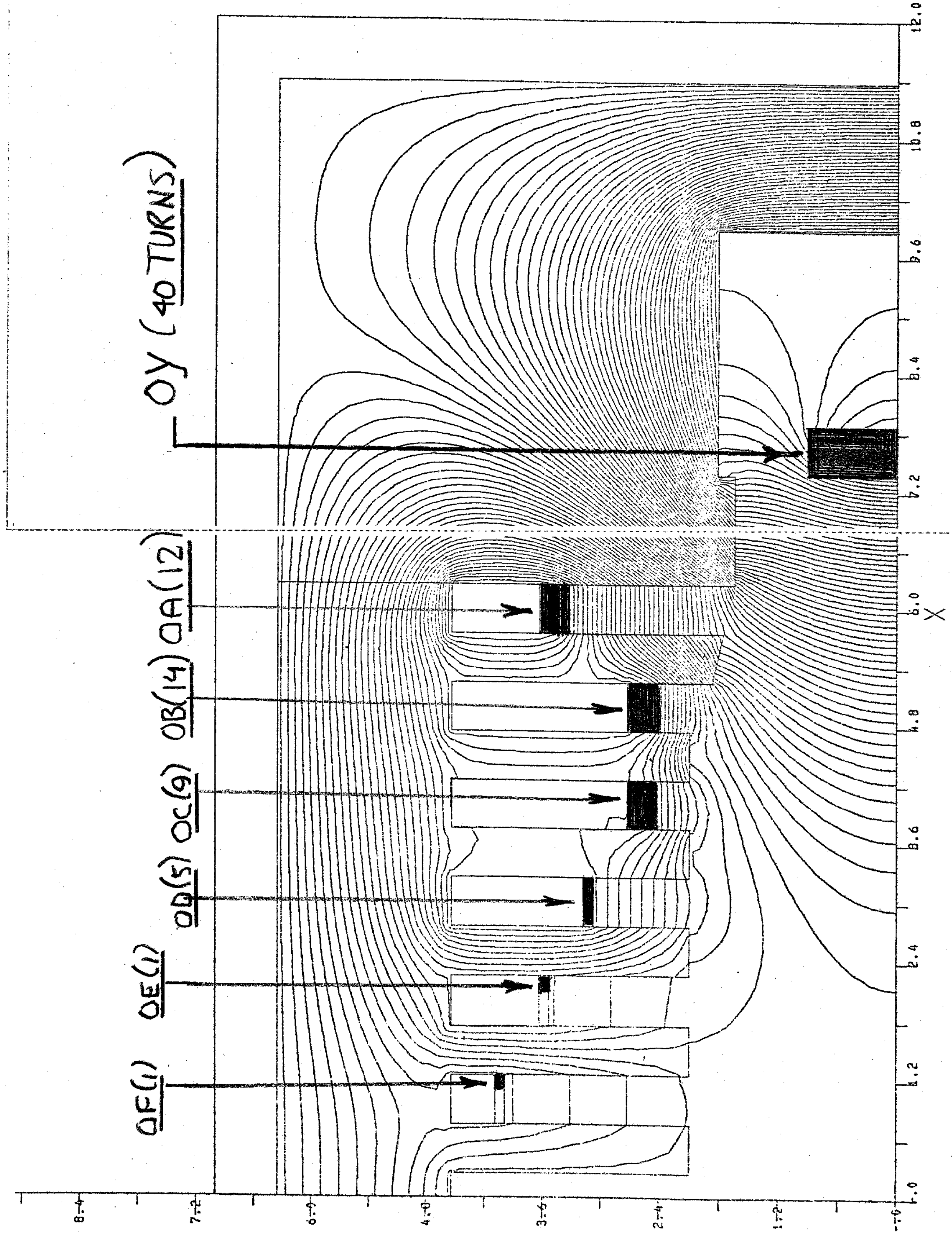


FIGURE V Octupole coil array and resulting flux distribution.

OCTUPOLE FIELD QUALITY (Model IV)

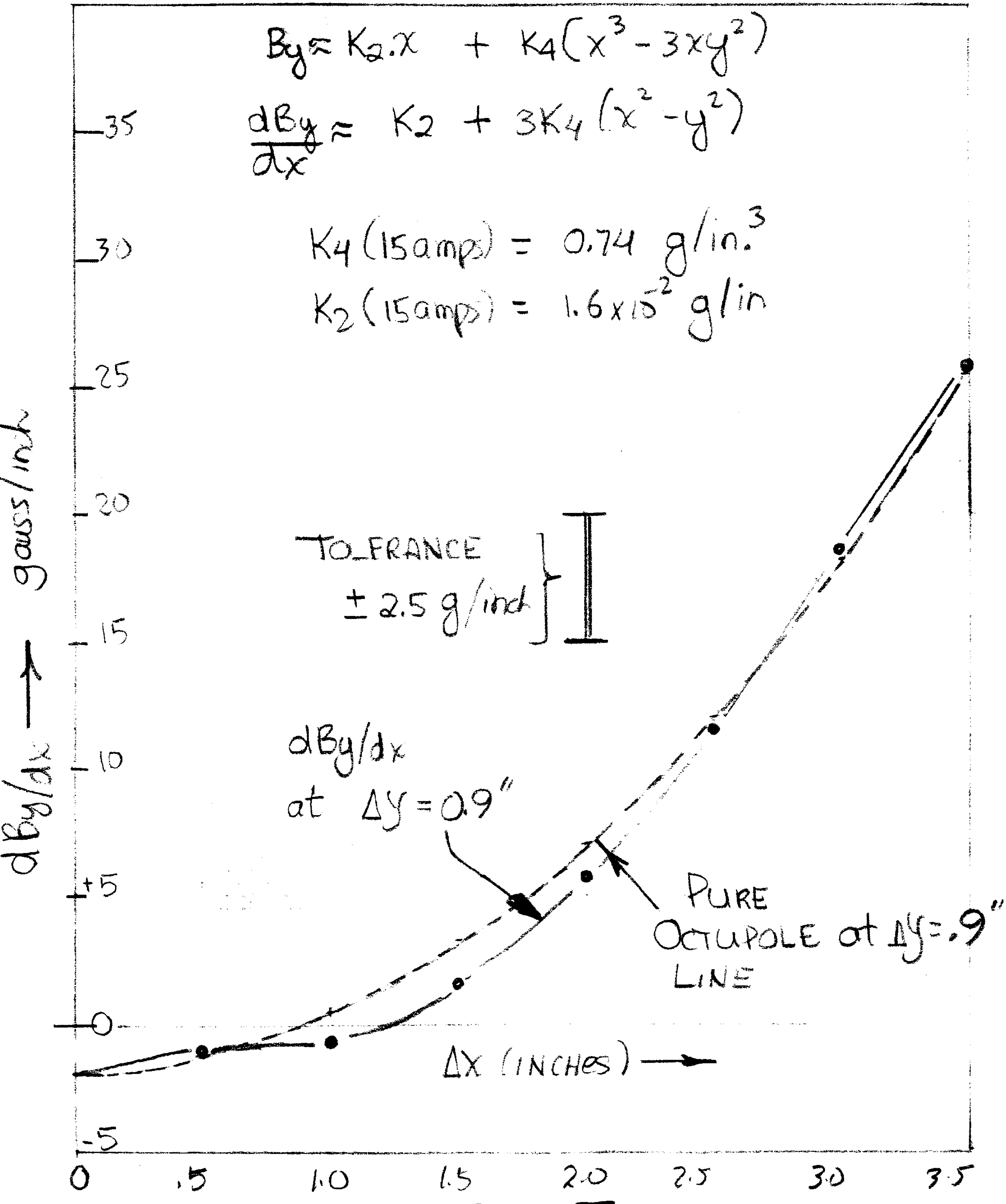


figure VI