MAGNET DIVISION NOTE

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Fringe Field Computations for SSC Design D Magnet

R. C. Gupta and G. H. Morgan

Introduction

In this note we present the fringe field calculations for the SSC Design D magnet with the code MDP and POISSON. We also study the effect of approximating a near 1/r current distribution in the coils to a constant current distribution, as happen in the above computer codes.

SSC Design D uses the C5 coils. The coil structure has been described in detail in Ref. 1. The coil structure on MDP is shown in Fig. 1. To adopt this structure on a model on POISSON, a few approximations are necessary. These approximations have been described in detail in Ref. 2. It should be pointed out that the magnet described in Ref. 2 has a different iron yoke. The present model on POISSON is shown in Fig 2 and the mesh used to create this model is shown in Fig 3. The mesh has 5476 nodes and a typical run takes about 25 minutes of VAX CPU time.

Calculations of the fringe fields

The fringe fields have been computed for 6400 Amps current in the coils. First we discuss the fringe fields on the median plane (on the X - axis). The results of the MDP run for this current is shown in Fig 4. The similar computations have been carried out with the code POISSON. In the code POISSON one needs to specify a boundary condition (either Neumann or Dirichlet or in general a combination of both). The fringe fields depend on specifing a type of boundary condition. We have studied the effect of these boundary conditions (at the right side of the mesh) on the fringe fields. Each boundary condition represents a different type of situation. In particular, a Neumann boundary (magnetic field lines perpendicular to the boundary) can be used to simulate the fringe fields between the two side by side magnets with the field in them in the opposite directions. similarly, a Neumann boundary (magnetic field lines parallel to the boundary) can be used to simulate the fringe fields between the two magnets with the fields in the same directions. In all cases the boundary has been taken at 35 cm to represent a 70 cm center to center distance between the two magnets. In Fig 5 we plot the fringe fields on the median plane for the Neumann and Dirichlet boundary conditions.

In Fig 6 we plot the fringe fields along the Y - axis (the vertical plane - the plane perpendicular to the median plane). The results have been computed from both MDP and POISSON codes and both are shown in that figure. In the SSC Design D, the two magnets are one above another and the field in them is in the opposite directions. The center to center distance between the two magnets is 70 cm. To simulate this situation on a model on POISSON the Dirichlet condition has been used for the upper boundary and the boundary is placed 35 cm above the median plane. To simulate this condition using MDP, the fields due to the two magnets are computed separately and then added.

Approximation to the current distribution in the coils

The computer codes, both MDP and POISSON, represent a slightly different current distribution in the coils than what is present in the actual case due to reasons mentioned below. These programs presume a constant current distribution in the coils which is not true in the case of keystoned cables. Due to keystoning, the area of the cable gets reduced on the inner side of the coil whereas the partial current going thru that side still remains the same as if the area was not reduced. This effectively increases the current density on the inner side of the coil. The current density distribution in a coil becomes proportional to 1/r if the keystone angle is right so that the coil takes a shape of a radial sector.

We do the following in our POISSON model to counter the effect of the reduced area (and therefore to counter the effect of increased current density). We divide each coil into a "number" of smaller coils with each of those smaller coils having the same thickness. Moreover, all of these smaller coils carry the same current, despite the fact that the coils situated inside have a smaller area. This makes the current density higher in the inner coils while keeping the total current as before. If the "number" is large, the current density distribution, so created, will be quite close to the one in the actual case. To study this effect, we chose the number to be 4 (Fig 7). To save computer time the calculations are done for infinite permeability iron. We observe the change in harmonics due to these subdivisions when (a) the coils are not divided and (b) when the coils are divided. We see that the maximum change is in the transfer function, about a quarter of a percent. The harmonics remain same within one tenth of a prime unit. These numbers, the transfer function and the difference in harmonics, have been computed independently with analytic formulas. The results agree with the POISSON computations for the transfer function and for all harmonics except for the sextupole. The analytic formulas predict a change of .9 prime unit for sextupole. It should be mentioned that in POISSON the mesh structure was changed slightly in the process of dividing one coil into four coils. This might be a reason for the apparent disagreement in the sextupole harmonic.

For future use, we summarize the results of POISSON computations in Table 1. The harmonics are computed for the infinite mu case and for finite (and variable) mu case for 5900 and 6400 Amps current in the coils.

References

1. R. C. Fernow and G. H. Morgan, Coil Design for the 40 mm Collared SSC Dipole (SSC-C5), Technical Note No. 19.

2. Ramesh C. Gupta, Field Calculations for 40 mm SSC 2-IN-1 Magnet with the code POISSON, SSC Technical Note No. 33, (SSC-N-27).

3. G. H. Morgan, The 1-in-1 SSC Dipole with C5 Coils, SSC Technical Note No. 23.

Table 1.

The results of the field computations

I (Amps)	B (T)	B/I (T/kA)	b'_2 10^{-4}	b'_4 10^{-4}	b'_6 10^{-4}	b'_8 10^{-4}	b'_{10} 10^{-4}	b'_{12} 10^{-4}
Inf. mu	-	-	5.3	-.1	0.2	0.8	0.0	0.0
5900	5.984	1.0142	7.4	-.2	0.1	0.8	0.0	0.0
6400	6.459	1.0092	6.7	-.3	0.1	0.8	0.0	0.0

where the harmonics are defined as follows :

$$B = B_o + \sum_n b_n (r/r_o)^n \, , \qquad (n = 1,2,3,\ldots)$$

with r being the radius on the midplane and r_o the normalization radius.

These harmonics have been computed for 1 cm normalization radius.

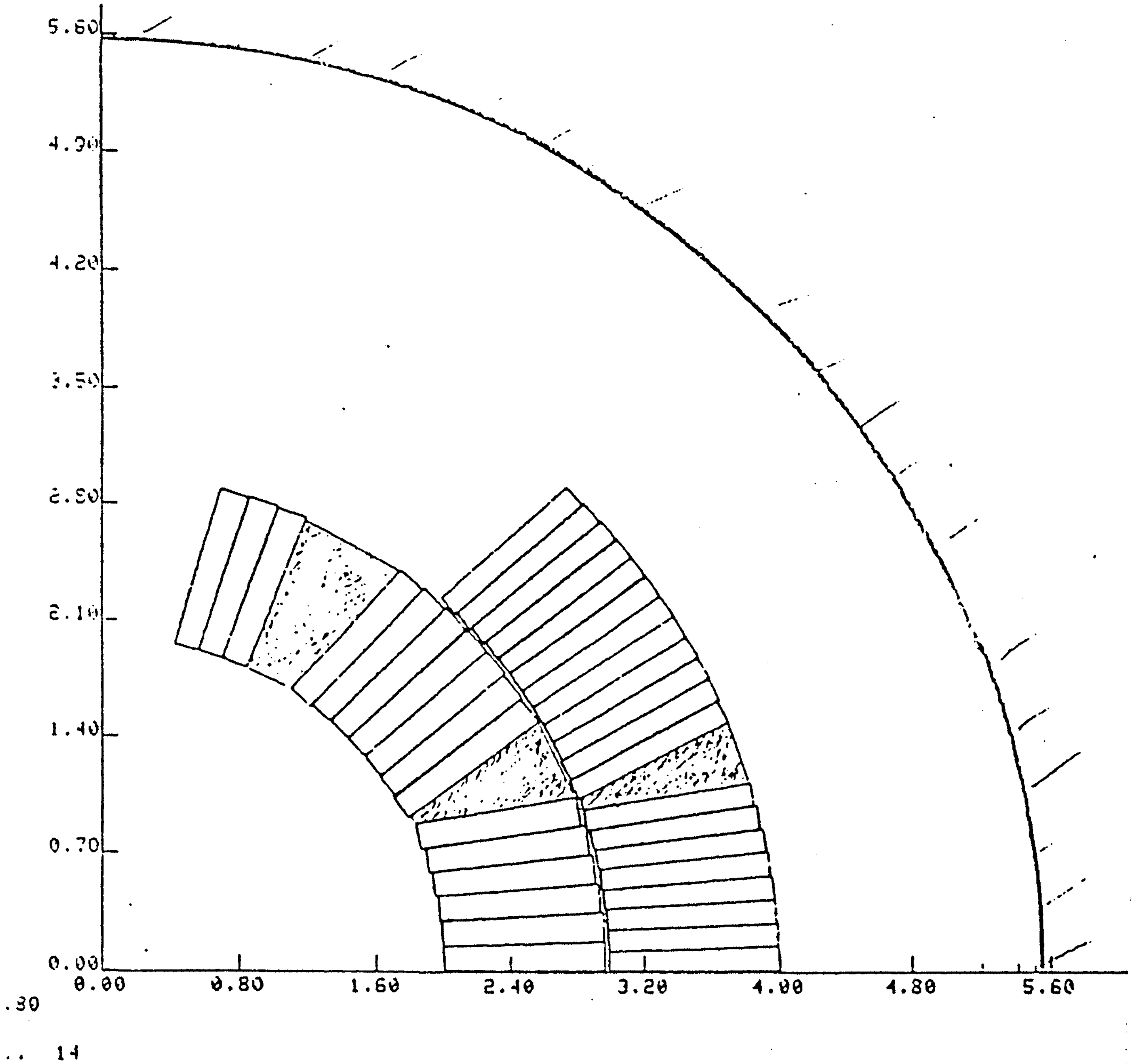

Fig 1. The original structure of the SSC - C5 coils. This geometry has been modified slightly to adopt it for a POISSON model.

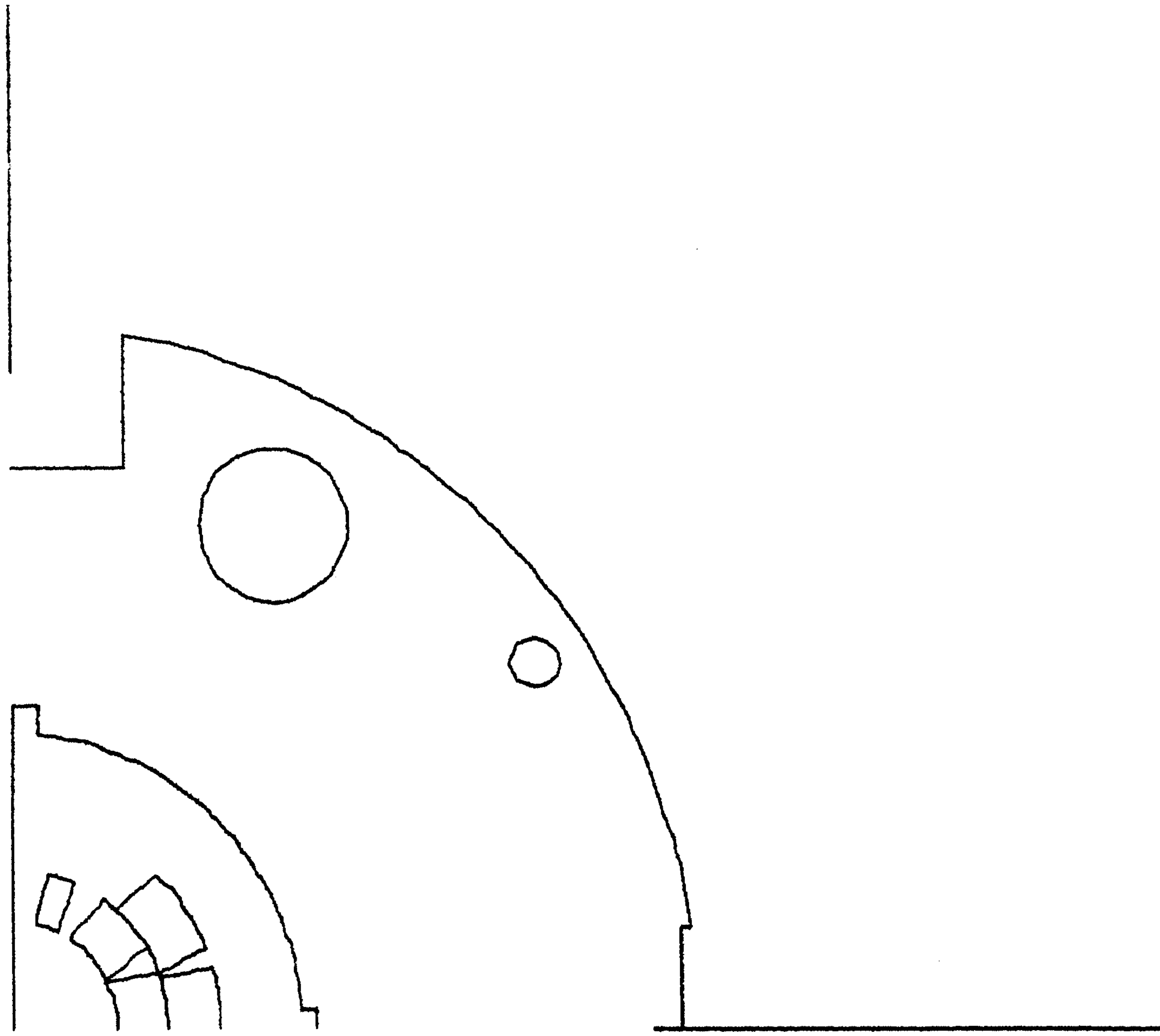

Fig. 2. The model on POISSON.

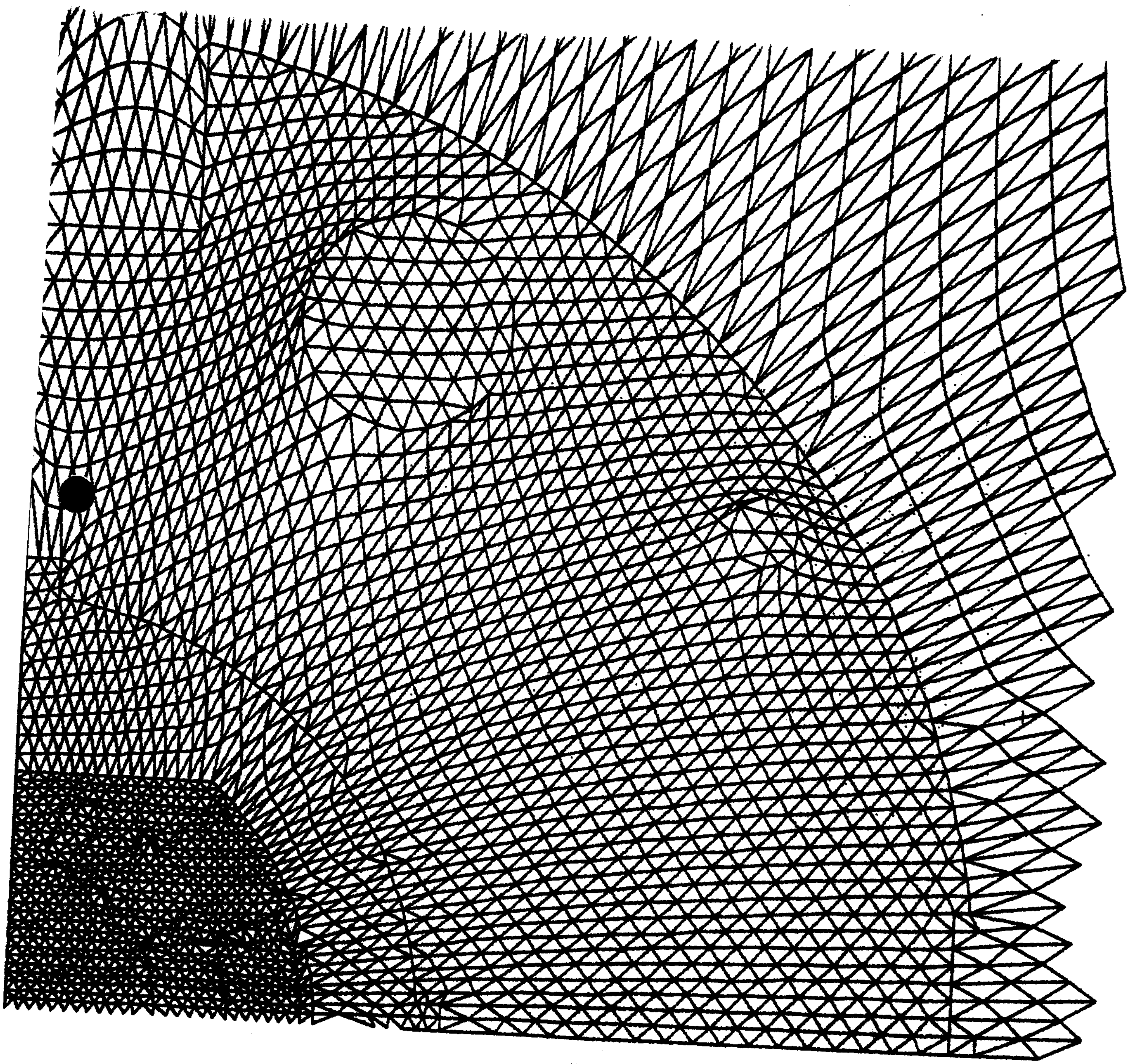

Fig 3. The mesh used to create a model on POISSON. The figure does not have complete mesh of the air region out side the iron. The mesh in that region vary slightly depending on the type of boundary condition used.

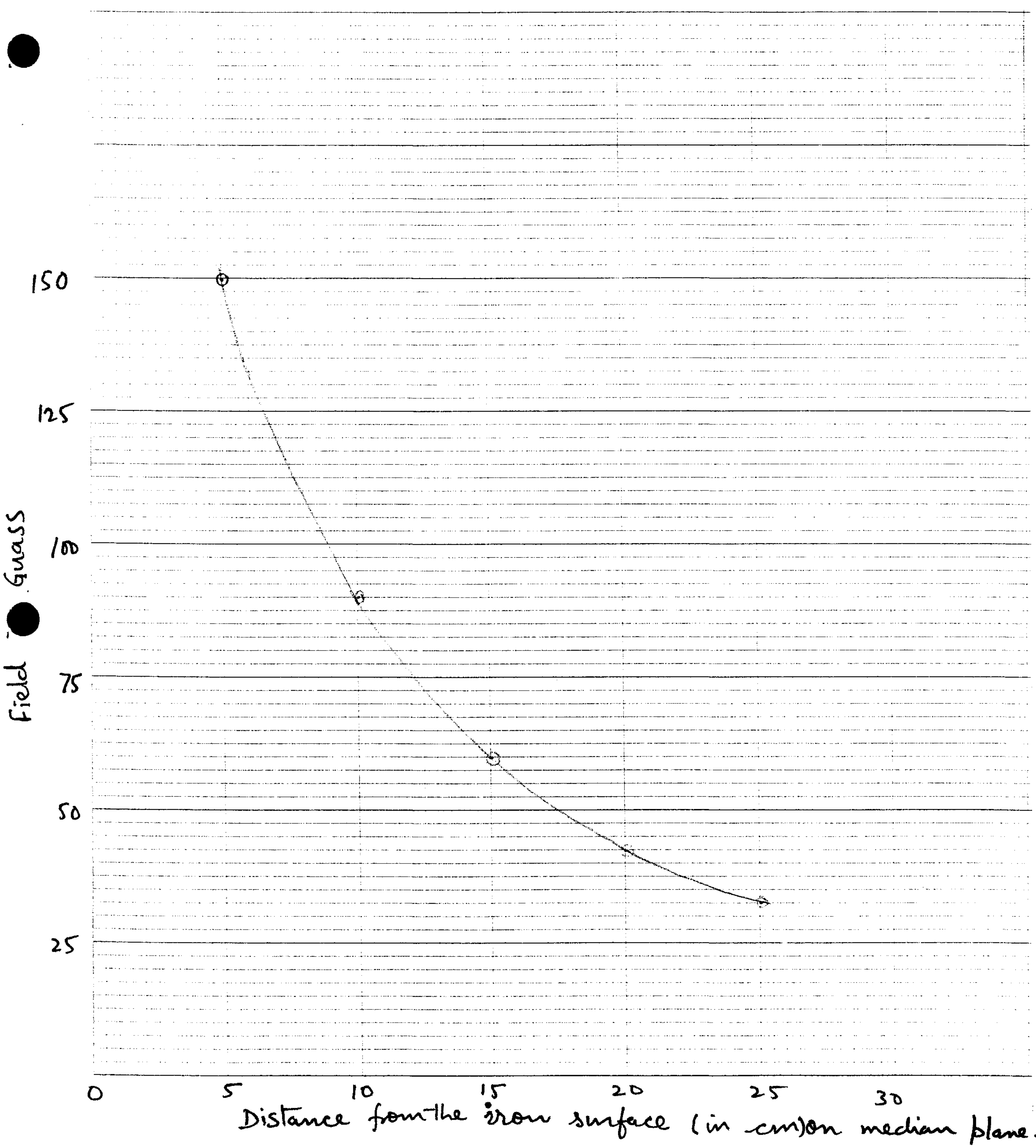

Fig. 4. Fringe field computations with the code MDP.

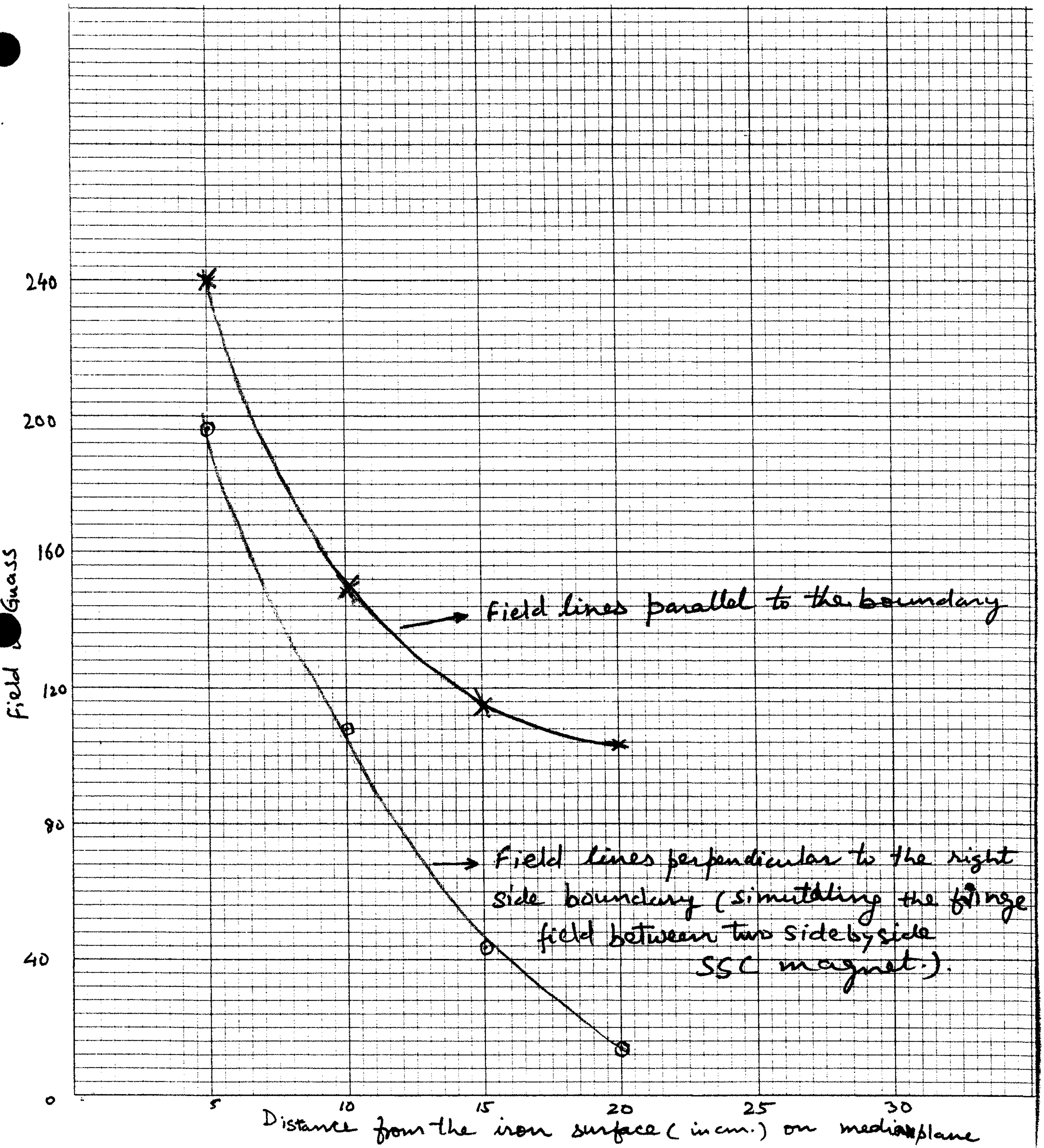

Fig. 5. Fringe field computations with the code POISSON The results are for 6400 Amps. current in the coils. The dependence of the fringe fields on the boundary condition is also shown.

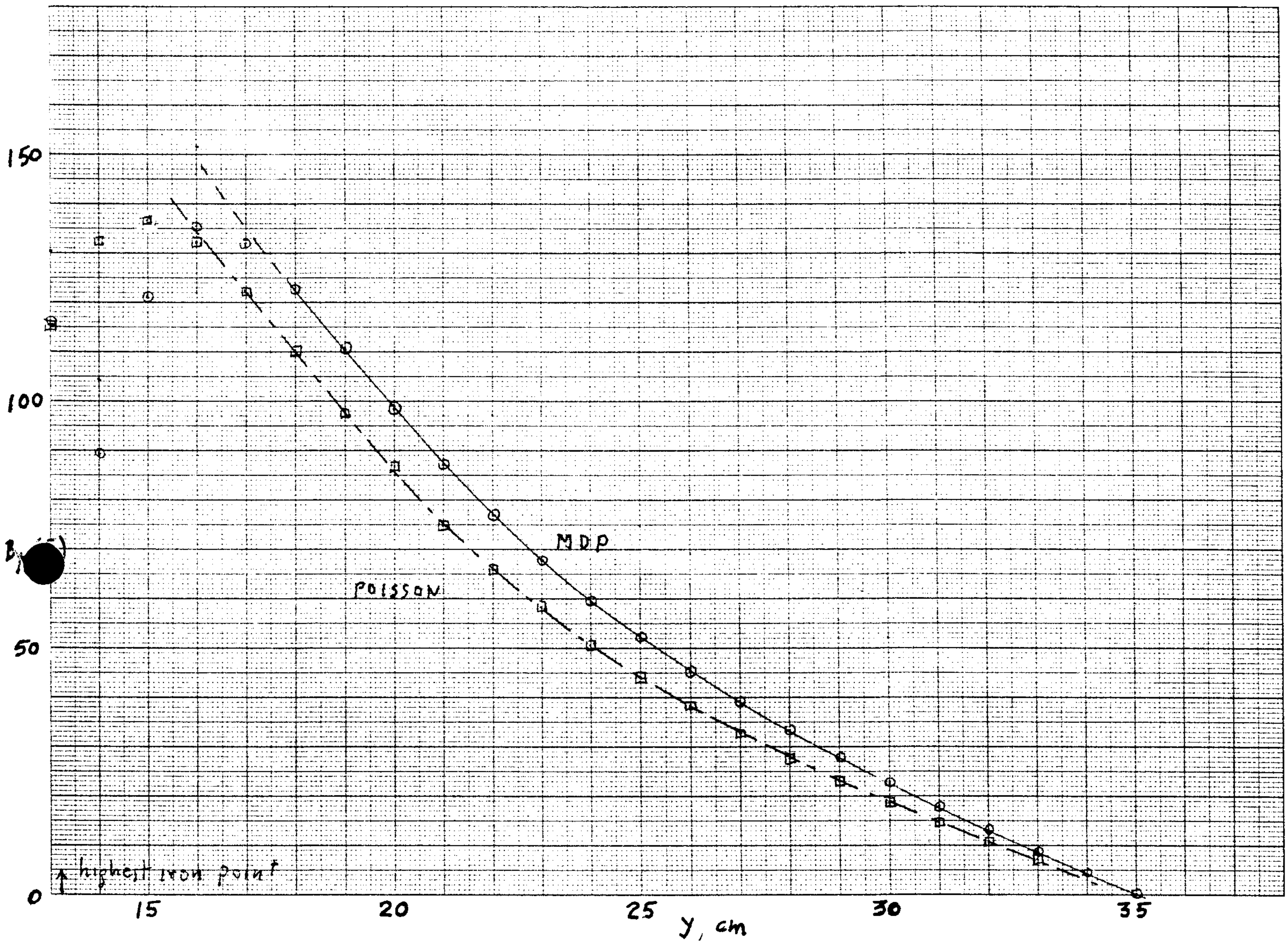

Fig 6. The Fringe field along the Y - axis (vertical plane).
The two plots are the results of calculations from
the computer codes MDP and POISSON.

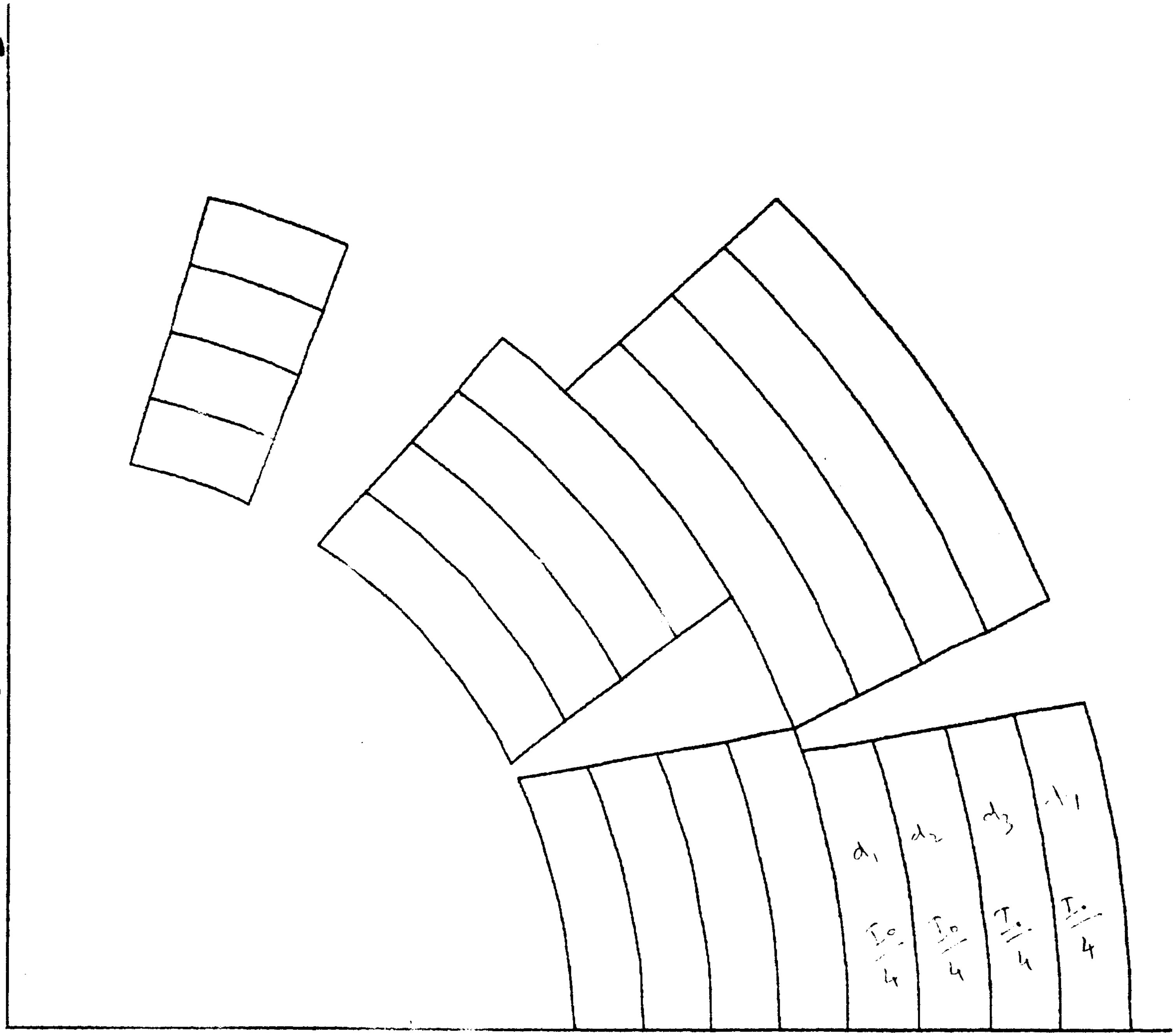

Fig. 7. Each coil has been divided into four coils as shown here. This is to approach a more realistic current distribution in the coils.