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Field Calculations for 40 mm SSC 2-IN-1 Magnet with the code POISSON

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Introduction

The results of the field computations on the 40 mm 2-in-1 SSC magnet are given here for balanced (same magnitude) and unbalanced (different magnitude) currents in the two sides of the dipole. In the balanced case the calculations are carried out from low field (field at injection) to high field (maximum field : 6.75 T) and in the unbalanced case at the field near injection. The coil geometry is the same as in Tech Note No. 19, namely SSC-C5 <1>. The iron cross section is as shown in the drwg 22-220.03. The computer code POISSON <2> is used to perform the field computations. It solves the differential equation (Poisson Equation) by successive point overrelaxation method.

The Model

In a complex geometry such as this, the major part of solving the problem is to translate the geometry of the magnet into a model on POISSON with sufficient accuracy. This is so because one has to match many curved and irregular boundaries of the coils and of the iron yoke to an initially triangular mesh used to describe the model. In principle, the grid size can be made small enough to incorporate all details of the given magnet into a model but in practice it is limited by excessive core memory and computational time requirements. Here these limitations are overcome partly by making acceptable approximations in the coil geometry and partly by modifying the mesh generating part (AUTOMESH) of the POISSON group codes to make more economic use of the available core size in setting up the model.

The actual coil is made up from a number of turns of partially keystoned conductors. The midpoints of the inner and outer edges of these conductor turns follow the reference radius of 1.999 cm and 2.962 cm for the inner coils, and 2.987 cm and 3.993 cm for the outer coils. The structure is shown in Fig 1. The structure is divided into five blocks, three in the inner layer and two in the outer. The inner blocks have respectively 6, 7 and 3 turns and the outer 8 and 12. The details of the configuration are given in SSC Tech Note No. 19.

In the first approximation we consider that the boundaries of the inner and outer coils coincide with the reference radius within each block. This approximation does not appear to modify the coil geometry seriously but it greatly simplifies constructing a model on POISSON. It removes the constraint that there must be a node on each corner of the every turn. In a second approximation we ignore the 0.15 mm separation between the inner and the outer coils and the 0.076 mm space from the midplane to the beginning of the coils. Though with the present mesh generator this approximation was not necessary, it saves substantial computer time without changing the results by an appreciable amount. The coil structure used in the model is summarized in Table 1. No other approximation was required to form the final model - none in the iron yoke structure. The right half of the model is shown in Fig 2.

Table 1. Coil Structure in the model on POISSON

Coordinates of the four corners of the coil-blocks (radius in cm, angle in degree) :

Inner coils

	Block 1 (C1)	Block 2 (C2)	Block 3 (C3)
1.	(2.014,0.0)	(2.014,27.267)	(2.014,64.962)
2.	(2.014,25.517)	(2.014,56.770)	(2.014,77.615)
3.	(2.987,20.463)	(2.987,53.836)	(2.987,76.349)
4.	(2.987,0.0)	(2.987,30.201)	(2.987,66.226)

Outer coils

	Block 4 (C4)	Block 5 (C5)
1.	(2.987,0.0)	(2.987,20.278)
2.	(2.987,18.789)	(2.987,48.198)
3.	(3.993,16.484)	(3.993,46.5)
4.	(3.993,0.0)	(3.993,21.975)

In the present version of POISSON one has to define one of the following two conditions at the end-boundaries of the mesh : (1) Neumann boundary condition magnetic field lines perpendicular to the boundary, (2) Dirichelet boundary condition - field lines parallel to the boundary. Since neither of the two is exactly satisfied on the outer boundaries, for which the Dirichelet condition is used, the outer boundary is chosen far away from the magnet so that its position produces no significant effect on the field at the center of the aperture. We have chosen it to be 7.2 cm away from the iron; the air space on the midplane is about twice the iron return leg thickness.

We have used midplane symmetry instead of quad symmetry in setting up the model for computations in the unbalanced case. The mesh is generated through the programs AUTOMESH and LATTICE. The mesh of the right half of the model is shown in Fig 3. It is very dense in the region where the coils are situated - the place where the structure is the most complex, irregular and has many finer details in it. At other places the mesh need not be so dense. This variable mesh density allows us to use available core memory efficiently. The density of the mesh is also reduced at the places where the field is low, especially in the air region just outside the magnet.

The Results

The results of the field computations are given in Table 2. The harmonics are computed at the center of the aperture for 1 cm normalization radius. It seems that in this calculation the harmonics are reliable to an accuracy of 0.5 X 10^{-4} prime units (worst case b_1'). In part (a) we examine the field harmonics and transfer function in the balanced case for the field near injection to 6.75 T (the magnet will operate below this field). The harmonics and transfer function below 4 T remain practically constant. The results of infinite mu computation are also given. In part (b) we examine the unbalanced case. The field in one leg is fixed at 0.325 T (the magnetic field near injection energy) and in the other leg either 3 or 5 times higher. The harmonics are not significantly different in the two legs; the difference in b_1' is less than 0.5 X 10^{-4} and in others practically none.

References

<1> R. Fernow and G. Morgan, "COIL DESIGN FOR THE LBL-SSC PROTOTYPE DIPOLE (SSC-B61)", SSC Technical Note No. 14.

<2> POISSON GROUP PROGRAMS USER'S GUIDE.

Table 2. The results of the field computations for 40 mm 2-in-1 dipole :

I (Amps)	B (T)	B/I (T/kA)	b'_1 10^{-4}	b'_2 10^{-4}	b'_3 10^{-4}	b'_4 10^{-4}	b'_5 10^{-4}	b'_6 10^{-4}
Case (a):								
Inf. mu	-	-	0.0	5.2	0.1	0.0	0.0	0.2
Upto								
3920	4.03	1.028	-0.4	5.4	0.1	-0.1	0.0	0.2
4480	4.60	1.027	-0.4	5.6	0.1	-0.1	0.0	0.2
5040	5.16	1.024	-0.1	6.0	0.1	-0.1	0.0	0.2
5600	5.71	1.020	-0.3	6.1	0.1	-0.1	0.0	0.2
6160	6.24	1.013	-0.9	5.8	0.1	-0.1	0.0	0.2
6720	6.75	1.004	-1.5	5.3	0.1	-0.1	0.0	0.2
Case (b):								
Ratio 1:3								
Low field	0.325	-	-0.1	5.2	0.1	0.0	0.0	0.2
High field	0.974	-	-0.3	5.2	0.1	0.0	0.1	0.3
Ratio 1:5								
Low field	0.325	-	-0.3	5.3	0.1	0.0	0.0	0.2
High field	1.624	-	0.2	5.3	0.1	0.0	0.0	0.3

where the harmonics are defined as follows :

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

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

These harmonics have been computed for 1 cm normalization radius.

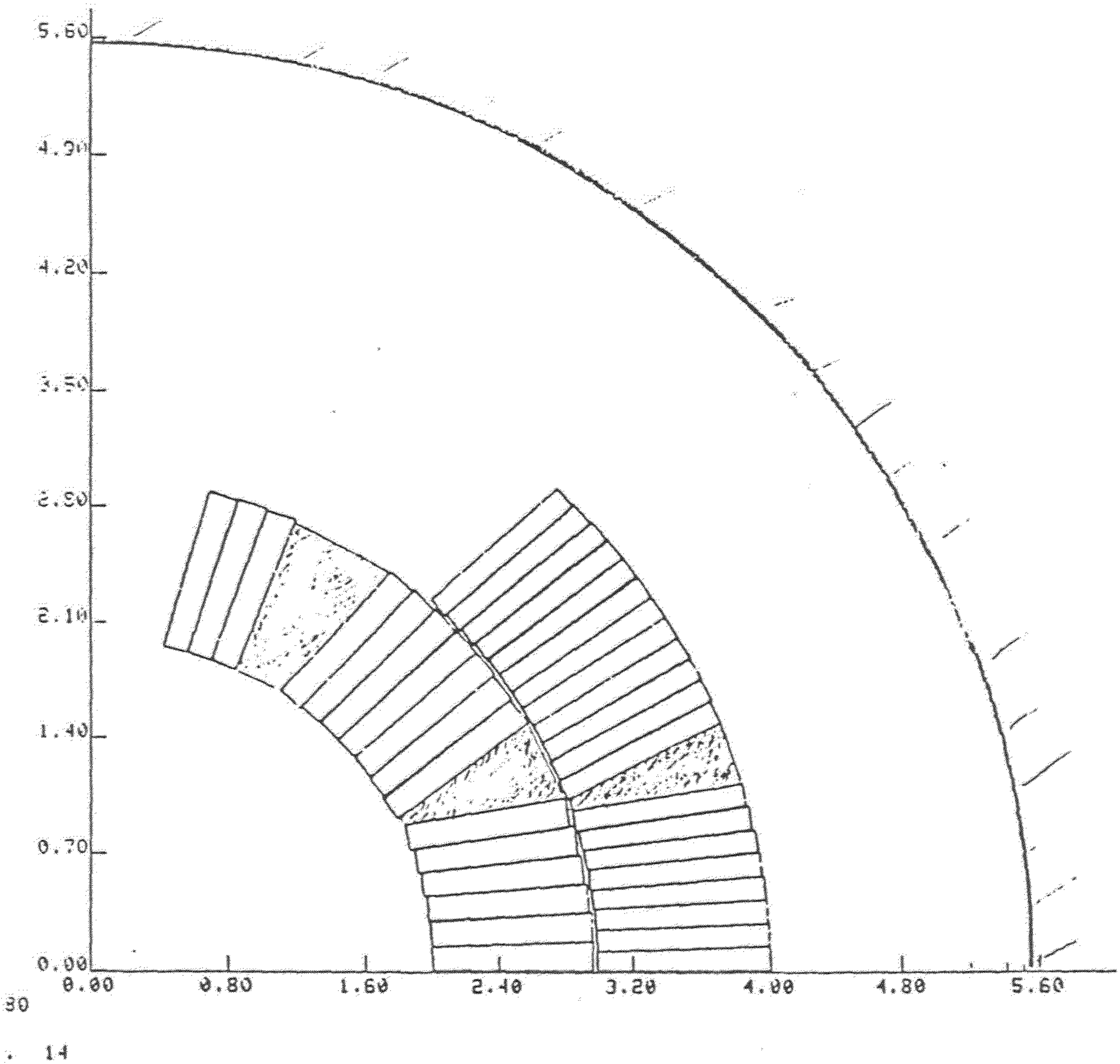

Fig 1. The original structure of the SSC - C5 coils. This geometry has been modified slightly to adopt it for a POISSON model.

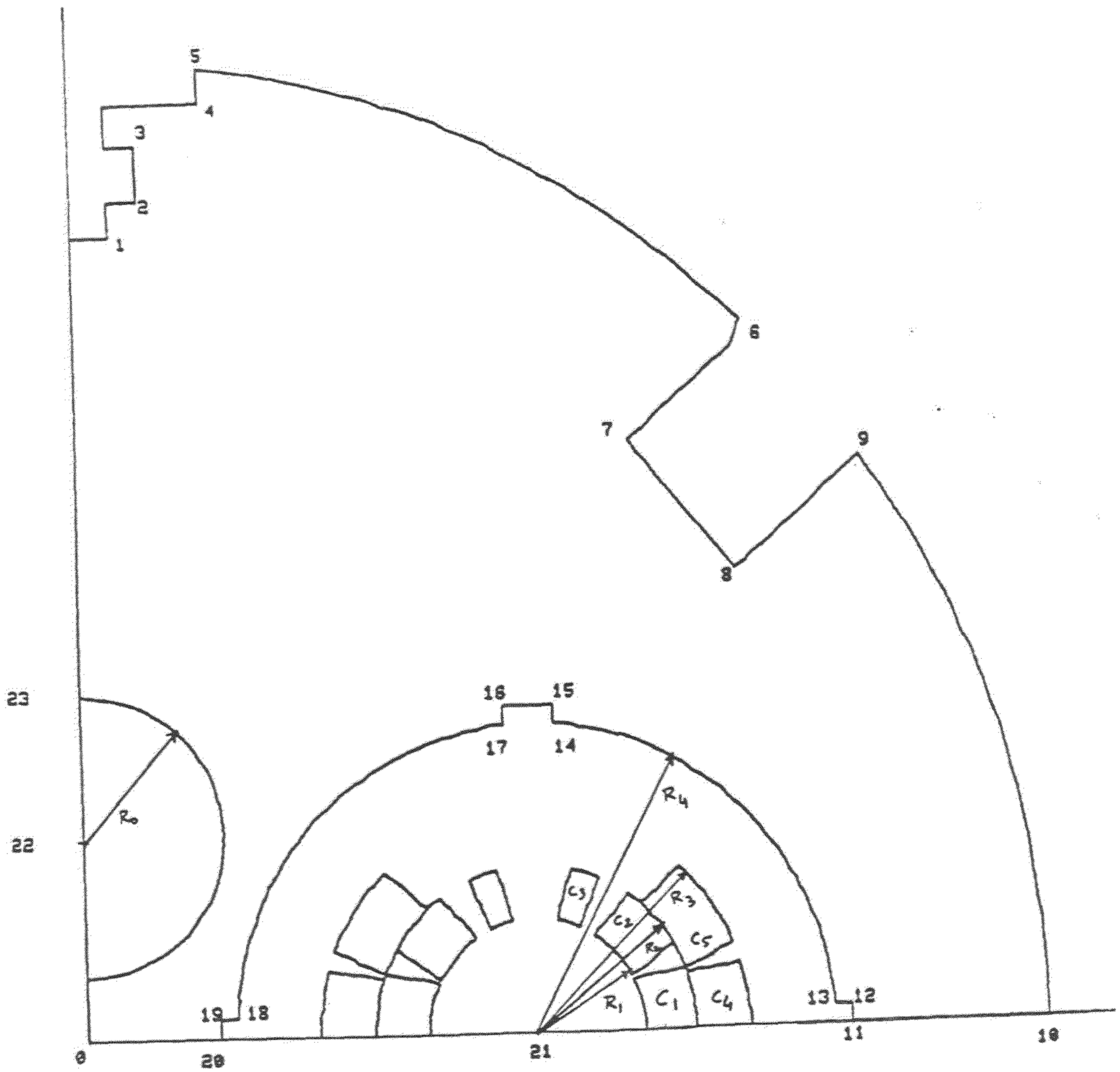

Fig 2. Right half of the model on POISSON.
The coordinates are in cm.

0 : (0.0,0.0)	8 : (12.222,8.268)	16 : (7.777,5.891)	R1=2.014
1 : (0.795,14.605)	9 : (14.557,10.226)	17 : (7.777,5.536)	R2=2.987
2 : (1.349,15.240)	10 : (17.790,0.0)	18 : (2.708,0.321)	R3=3.993
3 : (1.349,16.213)	11 : (14.134,0.0)	19 : (2.376,0.321)	R4=5.556
4 : (2.540,16.985)	12 : (14.134,0.321)	20 : (2.376,0.0)	R0=2.560
5 : (2.540,17.608)	13 : (13.802,0.321)	21 : (8.255,0.0)	
6 : (12.598,12.56)	14 : (8.7328,5.536)	22 : (0.0,3.6754)	
7 : (10.264,10.602)	15 : (8.7328,5.891)	23 : (0.0,6.2357)	

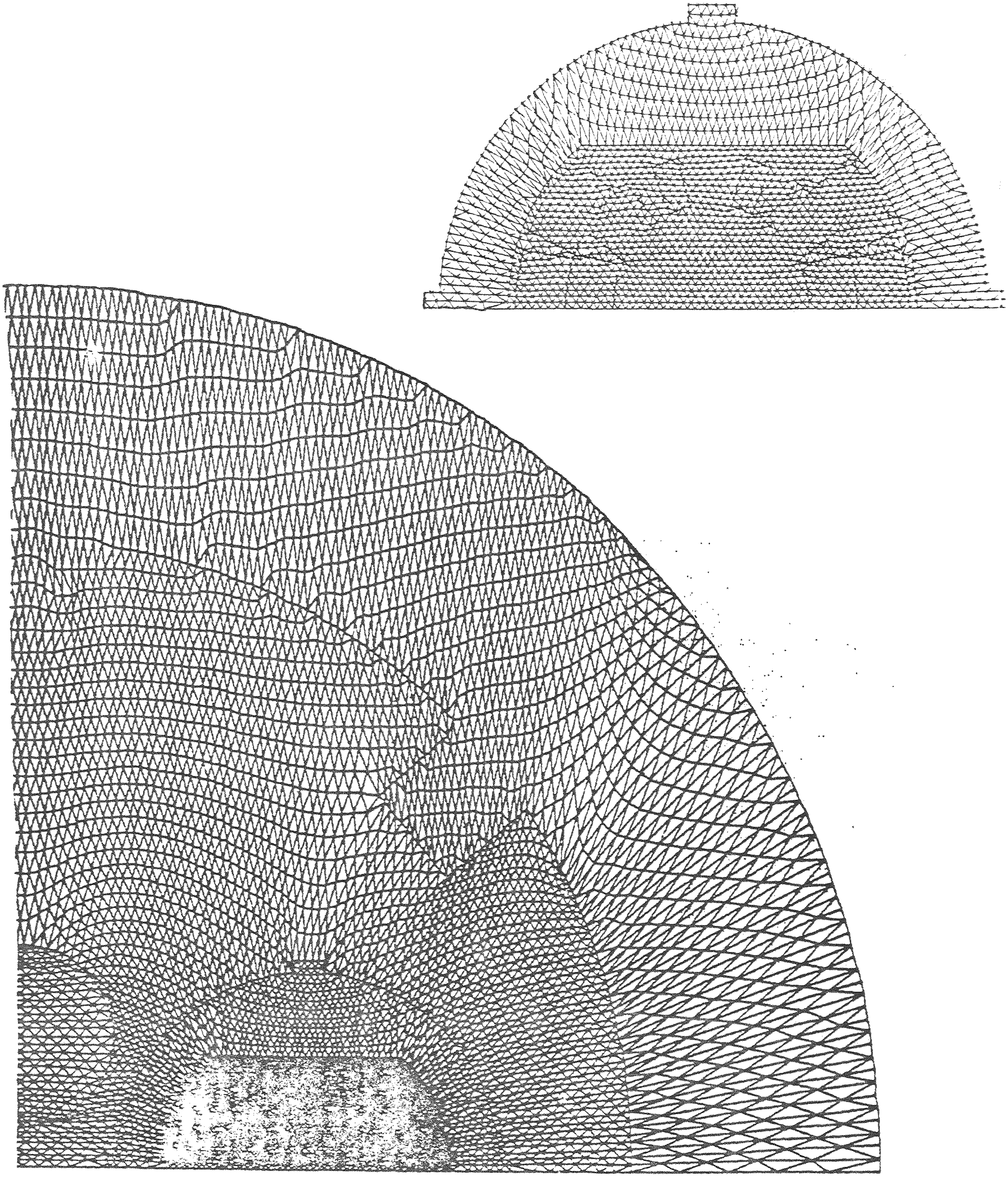

Fig 3. The mesh of the right half of the model on POISSON.
The mesh of the coil region is shown in more detail
seperately in the figure above.

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