Problem 7

Asymmetrical Conductor with a Hole

1. General Description

The model is shown in Fig.1. A thick aluminum plate with a hole, which is placed eccentrically, is set unsymmetrically in a non-uniform magnetic field. The field is produced by the exciting current which varies sinusoidally with time.

The problem is to calculate magnetic fields and eddy currents at various positions.

2. Mesh Description

As the model has no symmetry, the whole region should be discretized. The mesh shown in Fig.2 is recommended. If the discretization of the exciting coil is needed, the mesh shown in Fig.2 should be modified adequately. Though any kind of element is available, an attempt to keep the positions of the nodes and the elements shown in Fig.2 is encouraged.

3. Boundary Conditions

If the boundary conditions are needed, the outermost boundary which is away from the conductor is to be set on the positions shown in Fig.2. On the outermost boundary, the normal component of the flux density is to be equal to zero in order that the flux is parallel to the boundary. Please denote the imposed boundary conditions in Fig.3. In paticular, the boundary conditions of corners and edges of the conductor are to be denoted clearly.

4. Input Parameters

Input parameters are denoted in Table 1.

5. Quantities and Distributions to be Presented

To compare results, please complete Tables 2 and 3. Bz at f=0(Hz) in Table 2 means the field produced only by the exciting current. At ωt=0(deg), the exciting current becomes the maximum.

The following distributions are to be presented at ωt=0 and 90(deg).

(1) Distributions of flux density vectors on the x-z plane at y=72(mm).

(2) Distributions of eddy current vectors on the surfaces of the conductor at z=19 and 0(mm).

(3) Distributions of eddy current vectors in the x-z plane between 131<y<136(mm).

6. Description of Computer Program

To compare formulations, variables, etc., please complete Table 4. The used memory in the item No.15 is defined as the sum of dimensions declared in the program.

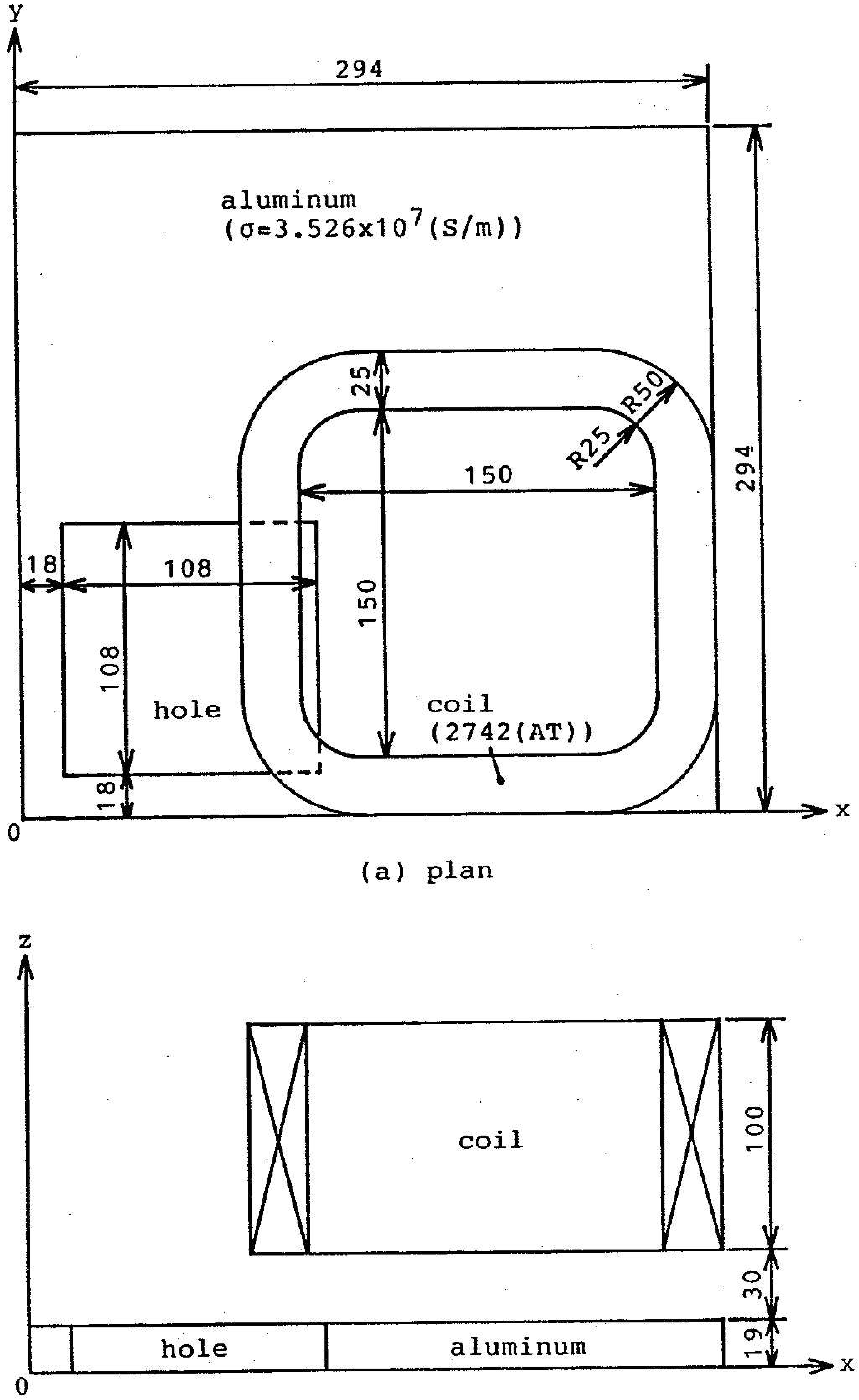
7. References

[1] D.Rodger & J.F.Eastham : "Multiply Connected Regions in the A-ψ Three-Dimensional Eddy-Current Formulation", IEE Proc. 134, Pt.A, 1, 58 (1987)

[2] T.Nakata, N.Takahashi, K.Fujiwara & Y.Okada : "Improvements of T-Ω Method for 3-D Eddy Current Analysis", IEEE Trans. Magnetics, MAG-24, 1 (1988)

[3] C.R.I.Emson : "Methods for the Solution of Open-Boundary Electromagnetic-Field Problems", IEE Proc. 135, Pt.A, 3, 151 (1988)

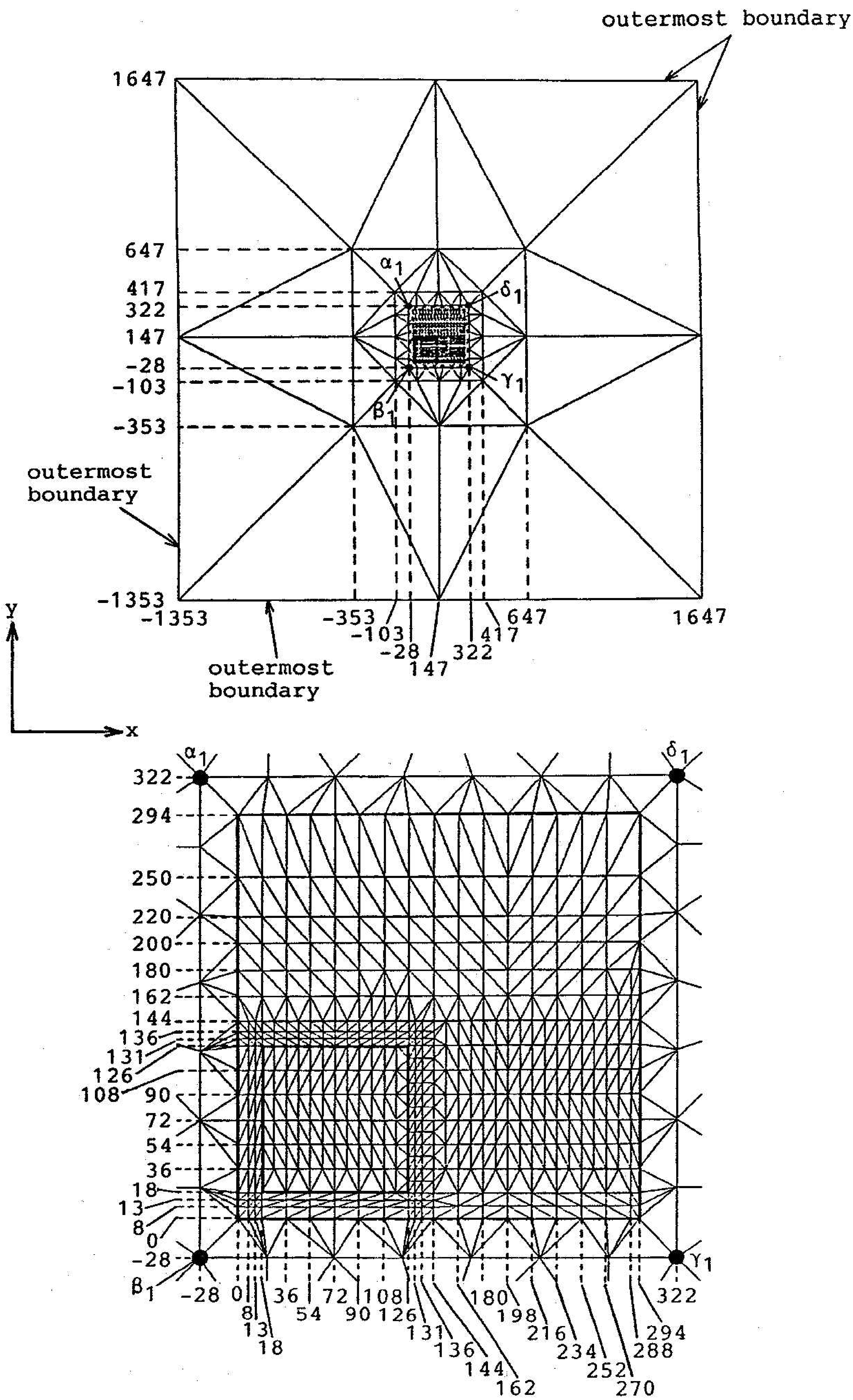
[4] P.Tong & J.N.Rossetos : "Finite-Element Method (Basic Technique and Implementation)", MIT Press (1977)



(a) plan

(b) cross-section

Fig.1 Asymmetrical conductor with a hole.



outermost boundary
1647
647
417
322
147
-28
-103
-353
-1353
α_1
δ_1
γ_1
β_1
outermost boundary
-1353
-353
-103
-28
147
322
417
647
1647
outermost boundary
y
x
322
294
250
220
200
180
162
144
136
131
126
108
90
72
54
36
18
13
8
0
-28
-28
0
8
13
18
36
54
72
90
108
126
131
136
144
162
180
198
216
234
252
270
288
294
322

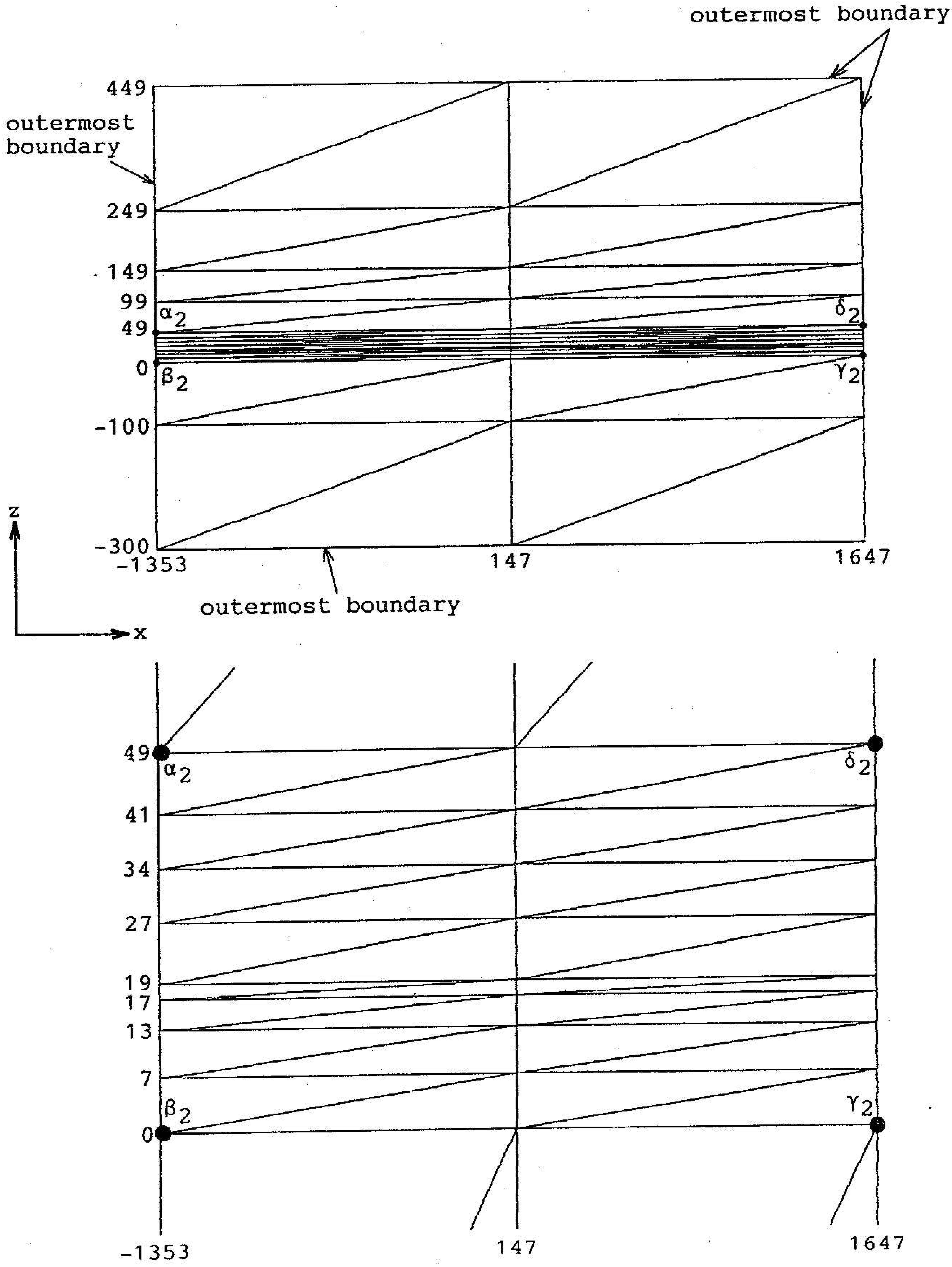
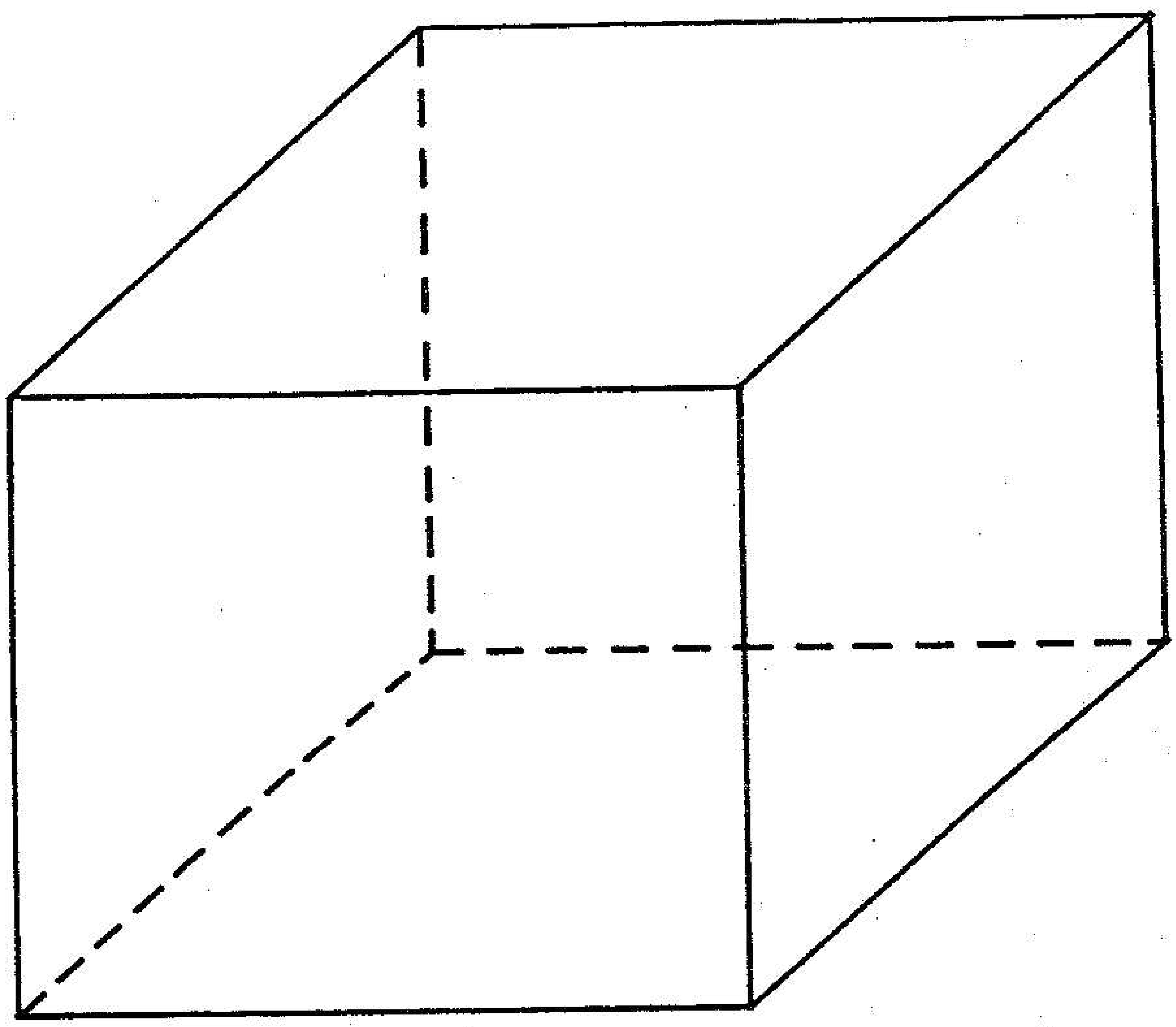
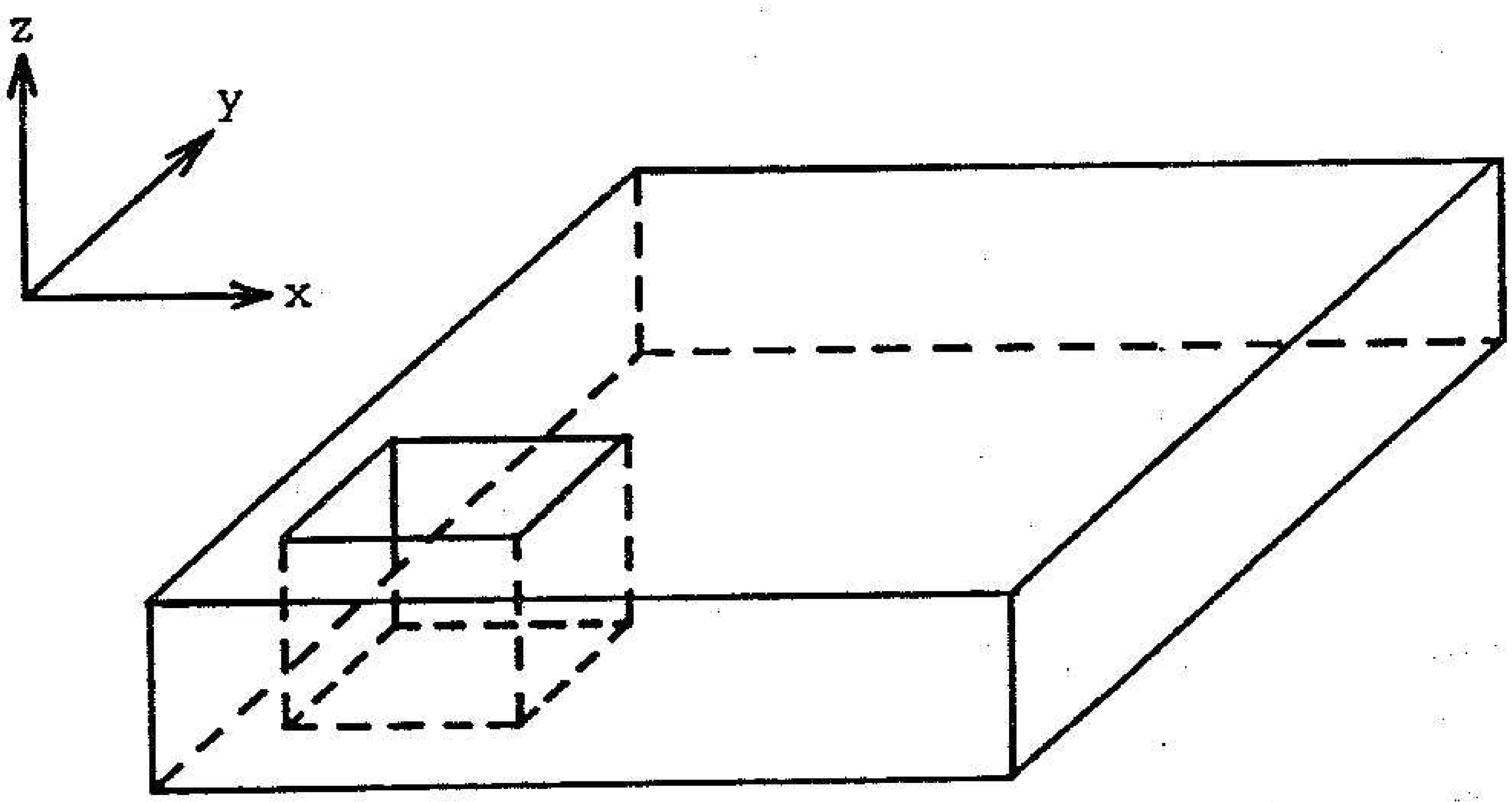


Fig.2(b) Recommended mesh on the x-z plane.



(a) outermost boundary



(b) surface of conductor

Fig.3 Boundary conditions.

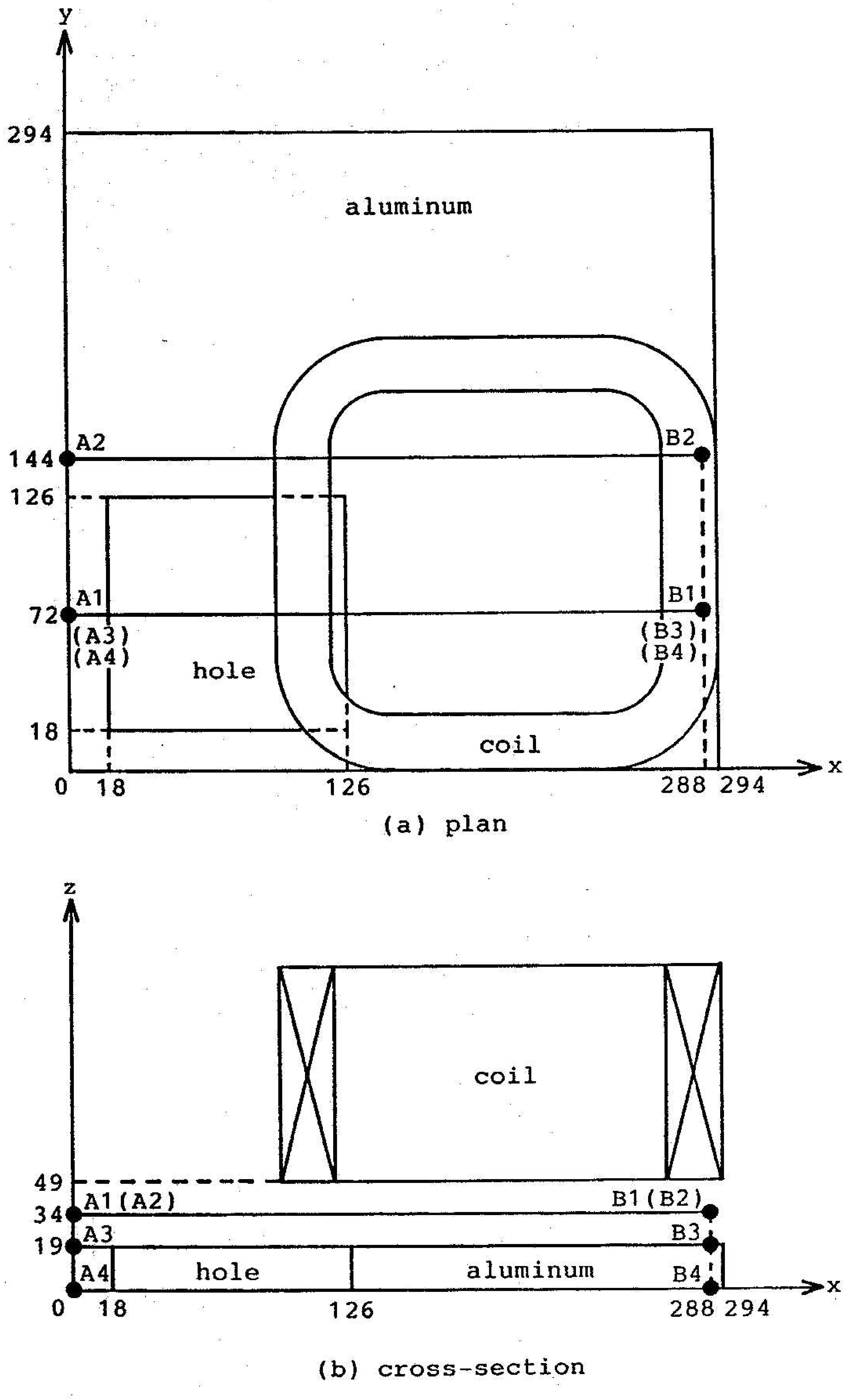


Fig.4 Measured points of the flux density and the eddy current density.

Table 1 Input parameters.

Parameter	Value
Conductivity σ (S/m)	3.526×10^7
Exciting current I_0 (AT)	2742
Frequency f (Hz)	50, 200

Table 2 Z-component Bz(Gauss) of the flux density along the lines A1-B1(y=72,z=34(mm)) and A2-B2(y=144,z=34(mm)) at the instances of ωt=0 and 90(deg).

(a) Bz along the line A1-B1(y=72,z=34(mm))

No.	x(mm)	f (Hz)				
		0	50		200	
			ωt=0	ωt=90	ωt=0	ωt=90
1	0.0					
2	18.0					
3	36.0					
4	54.0					
5	72.0					
6	90.0					
7	108.0					
8	126.0					
9	144.0					
10	162.0					
11	180.0					
12	198.0					
13	216.0					
14	234.0					
15	252.0					
16	270.0					
17	288.0					

(b) Bz along the line A2-B2(y=144,z=34(mm))

No.	x(mm)	f (Hz)			
		50		200	
		ωt=0	ωt=90	ωt=0	ωt=90
1	0.0				
2	18.0				
3	36.0				
4	54.0				
5	72.0				
6	90.0				
7	108.0				
8	126.0				
9	144.0				
10	162.0				
11	180.0				
12	198.0				
13	216.0				
14	234.0				
15	252.0				
16	270.0				
17	288.0				

Table 3 Y-component Jey($\times 10^6$ (A/m^2)) of the eddy current density along the lines A3-B3(y=72,z=19(mm)) and A4-B4(y=72,z=0(mm)) on the surfaces of the conductor at the instances of ωt=0 and 90(deg).

(a) Jey along the line A3-B3(y=72,z=19(mm))

No.	x(mm)	f (Hz)			
		50		200	
		ωt=0	ωt=90	ωt=0	ωt=90
1	0.0				
2	18.0				
3	36.0				
4	54.0				
5	72.0				
6	90.0				
7	108.0				
8	126.0				
9	144.0				
10	162.0				
11	180.0				
12	198.0				
13	216.0				
14	234.0				
15	252.0				
16	270.0				
17	288.0				

(b) Jey along the line A4-B4(y=72,z=0(mm))

No.	x(mm)	f (Hz)			
		50		200	
		ωt=0	ωt=90	ωt=0	ωt=90
1	0.0				
2	18.0				
3	36.0				
4	54.0				
5	72.0				
6	90.0				
7	108.0				
8	126.0				
9	144.0				
10	162.0				
11	180.0				
12	198.0				
13	216.0				
14	234.0				
15	252.0				
16	270.0				
17	288.0				

Table 4 Description of computer program.

No.	Item		Specification
1	Code name		
2	Formulation		☐ 1. FEM (Finite Element Method) ☐ 2. BEM (Boundary Element Method) ☐ 3. FECM (Finite Element Circuit Method) ☐ 4. NMM (Network Mesh Method) ☐ 5. IEM (Integral Equation Method) ☐ 6. FDM (Finite Difference Method) ☐ 7. combination (+) ☐ 8. the others ( ) (Please write references in the item No.16)
3	Governing equations	in conductor	
		in vacuum	
4	Solution variables	in conductor	
		in vacuum	
5	Gauge condition		☐ 1. not imposed 2. imposed ☐ (a) impose the condition on governing equations directly ☐ (b) penalty function method ☐ (c) Lagrange multiplier method ☐ (d) the others ( ) (Please write references in the item No.16)
6	Technique for treating hole in conductor[1]		☐ 1. no special technique ☐ 2. very low conductivity[2] (σ= (S/m)) ☐ 3. thin artificial conducting sheet (thickness= (mm)) ☐ 4. cut and potential jump ☐ 5. the others ( ) (Please write references in the item No.16)
7	Technique for open boundary problem[3]		☐ 1. truncation ☐ 2. mapping ☐ 3. ballooning ☐ 4. Zienkiewicz's infinite element ☐ 5. Tong's infinite element[4] ☐ 6. BEM or IEM ☐ 7. the others ((Please write references in the item No.16)

Table 4 Description of computer program (continued).

No.	Item	Specification
8	Magnetic field produced by exciting current	□ 1. Biot-Savart law (analytical) □ 2. Biot-Savart law (numerical) □ 3. taking into account exciting current in governing equations directly
9	Property of coefficient matrix of linear equations	1. symmetric □ (1a) sparse □ (1b) full 2. asymmetric □ (2a) sparse □ (2b) full □ 3. combination ( )
10	Solution method for linear equations	□ 1. ICCG □ 2. ICBCG □ 3. ILUBCG □ 4. SOR □ 5. LDL^T □ 6. LU □ 7. Gauss elimination method □ 8. the others ( ) (Please write references in the item No.16)
11	Element type	□ 1. tetrahedron (nodes, edges) □ 2. triangular prism (nodes, edges) □ 3. hexahedron (nodes, edges) □ 4. triangle (nodes, edges) □ 5. rectangle (nodes, edges) □ 6. the others ( )
12	Number of elements	
13	Number of nodes	
14	Number of unknowns	

Table 4 Description of computer program (continued).

No.	Item			Specification
15	Computer	name		
		speed		(MIPS), (MFLOPS)
		main memory (MB)		
		used memory (MB)		
		Precision of data (bits)		
		CPU time (sec)	total	
			solving linear equations	
16	References on Nos.2 to 10, etc.			

Y-components Jey($\times 10^6$ A/m^2) of eddy current densities on surface of conductor

(a) line A3-B3 (y=72mm, z=19mm)

No.	x(mm)	f(Hz)			
		50		200	
		ωt=0°	ωt=90°	ωt=0°	ωt=90°
1	0.0	0.249	-0.629	0.427	-0.623
2	18.0	0.685	-0.873	0.794	-0.755
3	126.0	-0.015	-0.593	1.401	-1.304
4	144.0	-0.103	-0.249	-0.035	-0.229
5	162.0	-0.061	-0.101	0.005	-0.041
6	180.0	-0.004	-0.001	-0.011	-0.014
7	198.0	0.051	0.087	0.007	-0.002
8	216.0	0.095	0.182	0.027	-0.000
9	234.0	0.135	0.322	0.042	0.008
10	252.0	0.104	0.555	0.043	0.033
11	270.0	-0.321	0.822	0.050	0.116
12	288.0	-0.687	0.855	-0.321	0.893

(b) line A4-B4 (y=72mm, z=0mm)

No.	x(mm)	f(Hz)			
		50		200	
		ωt=0°	ωt=90°	ωt=0°	ωt=90°
1	0.0	0.461	-0.662	1.057	-0.915
2	18.0	0.621	-0.644	1.597	-1.036
3	126.0	1.573	-1.027	4.163	-2.328
4	144.0	0.556	-0.757	1.143	-1.193
5	162.0	0.237	-0.364	0.672	-0.613
6	180.0	0.097	-0.149	0.307	-0.259
7	198.0	-0.034	0.015	-0.050	0.061
8	216.0	-0.157	0.154	-0.370	0.334
9	234.0	-0.305	0.311	-0.749	0.674
10	252.0	-0.478	0.508	-1.205	1.064
11	270.0	-0.660	0.747	-1.575	1.404
12	288.0	-1.217	1.034	-2.583	2.331

Z-components Bz(G) of flux densities

(a) line A1-B1 (y=72mm, z=34mm)

No.	x(mm)	f(Hz)			
		50		200	
		ωt=0°	ωt=90°	ωt=0°	ωt=90°
1	0.0	- 4.90	-1.16	- 3.63	-1.38
2	18.0	-17.88	2.84	-18.46	1.20
3	36.0	-22.13	4.15	-23.62	2.15
4	54.0	-20.19	4.00	-21.59	1.63
5	72.0	-15.67	3.07	-16.09	1.10
6	90.0	0.36	2.31	0.23	0.27
7	108.0	43.64	1.89	44.35	-2.28
8	126.0	78.11	4.97	75.53	-1.40
9	144.0	71.55	12.61	63.42	4.17
10	162.0	60.44	14.15	53.20	3.94
11	180.0	53.91	13.04	48.66	4.86
12	198.0	52.62	12.40	47.31	4.09
13	216.0	53.81	12.05	48.31	3.69
14	234.0	56.91	12.27	51.26	4.60
15	252.0	59.24	12.66	53.61	3.48
16	270.0	52.78	9.96	46.11	4.10
17	288.0	27.61	2.36	24.96	0.98

(b) line A2-B2 (y=144mm, z=34mm)

No.	x(mm)	f(Hz)			
		50		200	
		ωt=0°	ωt=90°	ωt=0°	ωt=90°
1	0.0	- 1.83	-1.63	- 0.86	-1.35
2	18.0	- 8.50	-0.60	- 7.00	-0.71
3	36.0	-13.60	-0.43	-11.58	-0.81
4	54.0	-15.21	0.11	-13.36	-0.67
5	72.0	-14.48	1.26	-13.77	0.15
6	90.0	-5.62	3.40	-6.74	1.39
7	108.0	28.77	6.53	24.63	2.67
8	126.0	60.34	10.25	53.19	3.00
9	144.0	61.84	11.83	54.89	4.01
10	162.0	56.64	11.83	50.72	3.80
11	180.0	53.40	11.01	48.03	4.00
12	198.0	52.36	10.58	47.13	3.02
13	216.0	53.93	10.80	48.25	2.20
14	234.0	56.82	10.54	51.35	2.78
15	252.0	59.48	10.62	53.35	1.58
16	270.0	52.08	9.03	45.37	1.37
17	288.0	26.56	1.79	24.01	0.93