DEUTSCHES ELEKTRONEN - SYNCHROTRON DESY

DESY 87-118
September 1987

COMPUTER AIDED TWO/THREE DIMENSIONAL MAGNET DESIGN BY MEANS OF PROFI

by

W.-R. Novender

Deutsches Elektronen-Synchrotron DESY, Hamburg

ISSN 0418-9833

NOTKESTRASSE 85 · 2 HAMBURG 52

DESY 87-118
September 1987

ISSN 0418-9833

Computer Aided Two/Three Dimensional Magnet Design by Means of PROFI

by

Wolf-Rainer Novender
Deutsches Elektronen-Synchrotron DESY, Hamburg

Computer Aided Two/Three Dimensional Magnet Design

by Means of PROFI

by

Wolf-Rainer Novender

1. Abstract

The paper describes the facilities of the computer code PROFI and its preprocessor PROFCOM with special regard to the two and three dimensional magnet design. Moreover the 3D geometry-modeling program SABRINA is outlined. Typical applications are presented.

2. Introduction

The computer code PROFI is a stand-alone numerical field calculation program [1]. Fig. 2.1 shows the software environment of this code, as it is used at DESY.

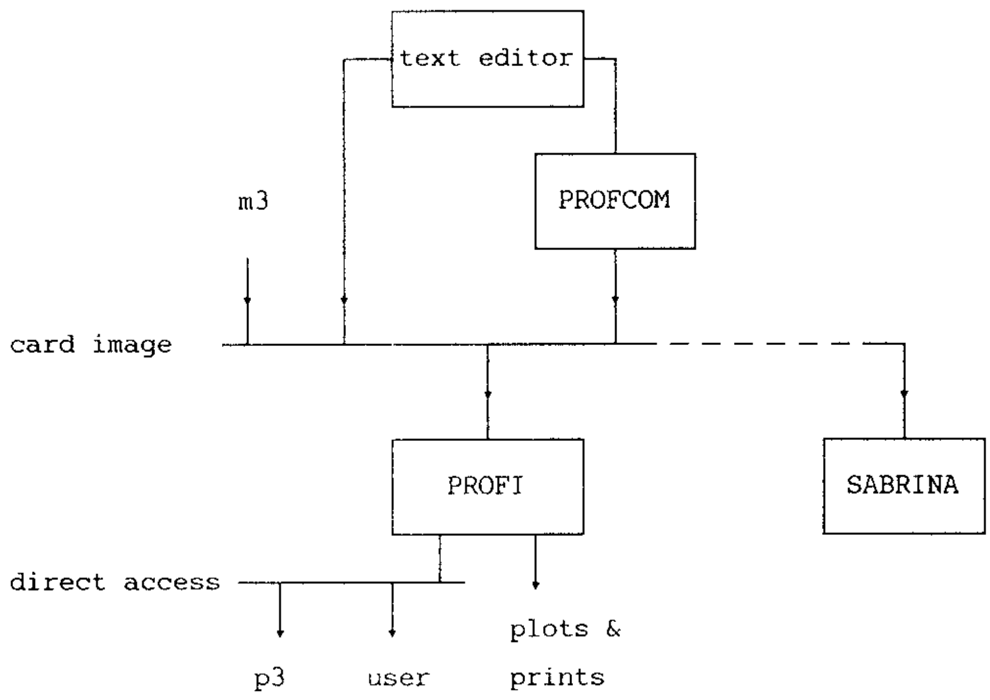

Fig. 2.1. PROFI software environment

The problem to be solved must be entered in a fixed format card image form. Additionally a FORTRAN main program and the appropriate job control statements must be provided using a standard text editor. Due to this tiresome input procedure the preprocessor PROFCOM was developed, which converts easy-to-remember free-format keywords into the strict PROFI format, creates the necessary FORTRAN main program and the complete JCL job.

For 3D problems the mesh generator M3 may be used to create the mesh, the material and the current filament distribution. The user may directly inspect his input data during the interactive terminal session. Once the problem is described M3 creates the PROFI input card deck. The user has to complete this deck with additional information like boundary conditions, material properties, iteration parameters etc..

Besides its own output print/plot routines PROFI may optionally store the results of the field calculations onto a direct access file, which may be processed by any other user written program or the postprocessor P3. This postprocessor offers many options for displaying 3D scalar and vector results and works completely interactively.

Actually M3 and P3 are the front/end processors of the MAFIA program package and are described elsewhere [2].

The interactive 3D geometry-modeling program SABRINA [3] produces high quality colour-shaded plots. At present there is no data link between SABRINA and the above mentioned codes. Only PROFCOM generates a basic set of input statements for SABRINA, which must be completed manually.

3. PROFI

Late in 1975 the development of a general purpose static field calculation program was started. This code later became known as PROFI. The present version 5.2 at DESY can handle the following nonlinear field problems:

- magnetostatic
- electrostatic
- temperature
- current distribution

within 5 different coordinate systems:

- 2D cartesian
- 2D polar
- 2D axially symmetric
- 3D cartesian
- 3D cylindrical.

The program uses the method of finite differences. The grid may be arbitrarily chosen by the user thus determining the accuracy of the material distribution and hence the accuracy of the results. Different boundary conditions may be used to take advantage of symmetries and periodicities in order to save computer time and memory. For magnetic field calculations, currents may be entered as current sheets or three dimensional polygons. Different materials with nonlinear properties may be entered. The linear equation system is solved iteratively by means of the SOR (successive overrelaxation) method. The accuracy of the results is controlled by different parameters. Convergence is practically guaranteed and has been achieved by problems with more than 140,000 mesh points [4], though certain magnetic conditions may slow down the iteration.

The problem size is only restricted by the available computer memory and CPU time. With the number N of mesh points the iteration time increases appr. proportional by $N^{3/2}$ for 2D and by $N^{4/3}$ for 3D problems. Under IBM's operating system, MVS, the region size needed is proportional to N and can be estimated from

region size = ((N * 8.6 + 200) * 8) / 1000 + 300 [kByte].

Primarily PROFI has been designed to run in a batch environment. The user has to prepare 3 files:

- a data file, which contains the problem description
- a small FORTRAN main program, which defines the workspace and calls for the appropriate subroutines (operators)
- a JCL (job control language) file, which performs the compile, link, and go steps. This file includes the data file and the FORTRAN program and contains the adjusted region, time and file parameters.

The drawback of this 3-steps procedure is outweighed by the advantage that the memory requirement can be minimized according to the problem size. Additionally the executable load module consists of only those subroutines needed for the actual calculation saving memory space again.

Fig. 3.1 to 3.7 show some results of two dimensional field calculations. The field plots are directly produced by PROFI.

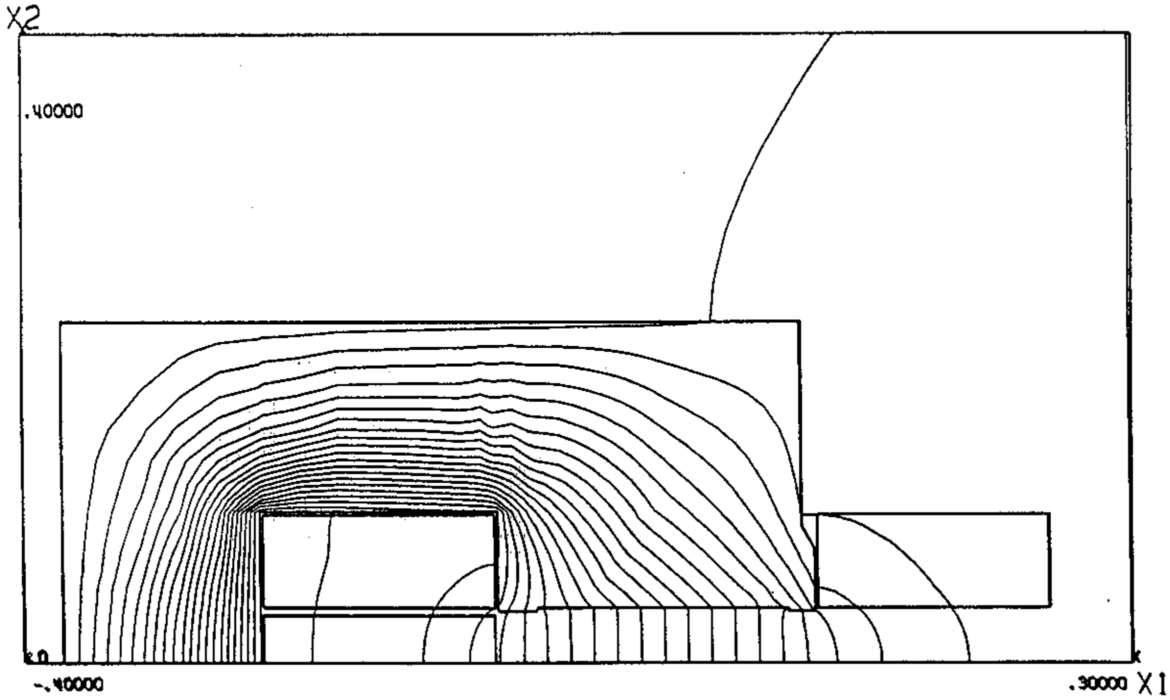

Fig. 3.1. Modified PETRA bending magnet

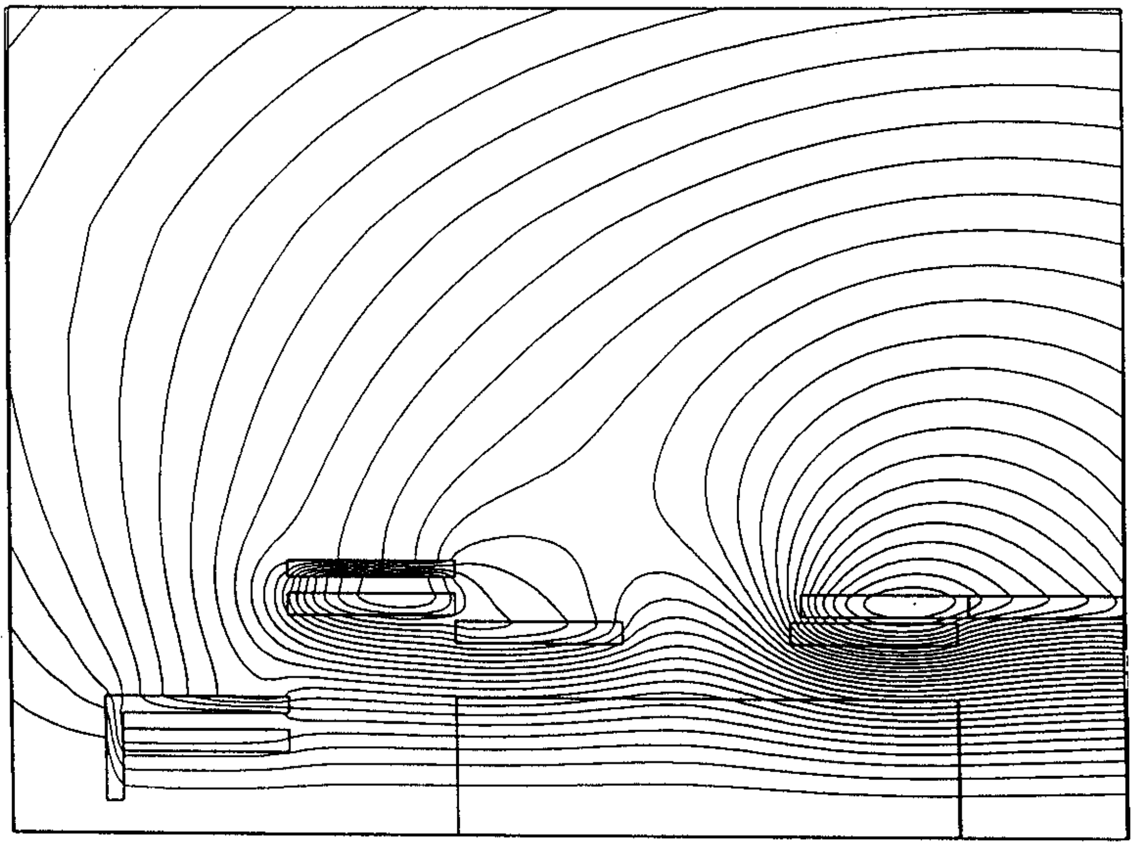

Fig. 3.2. Part of the hollow beam spectrometer of the Wake Field Transformer experiment [8]

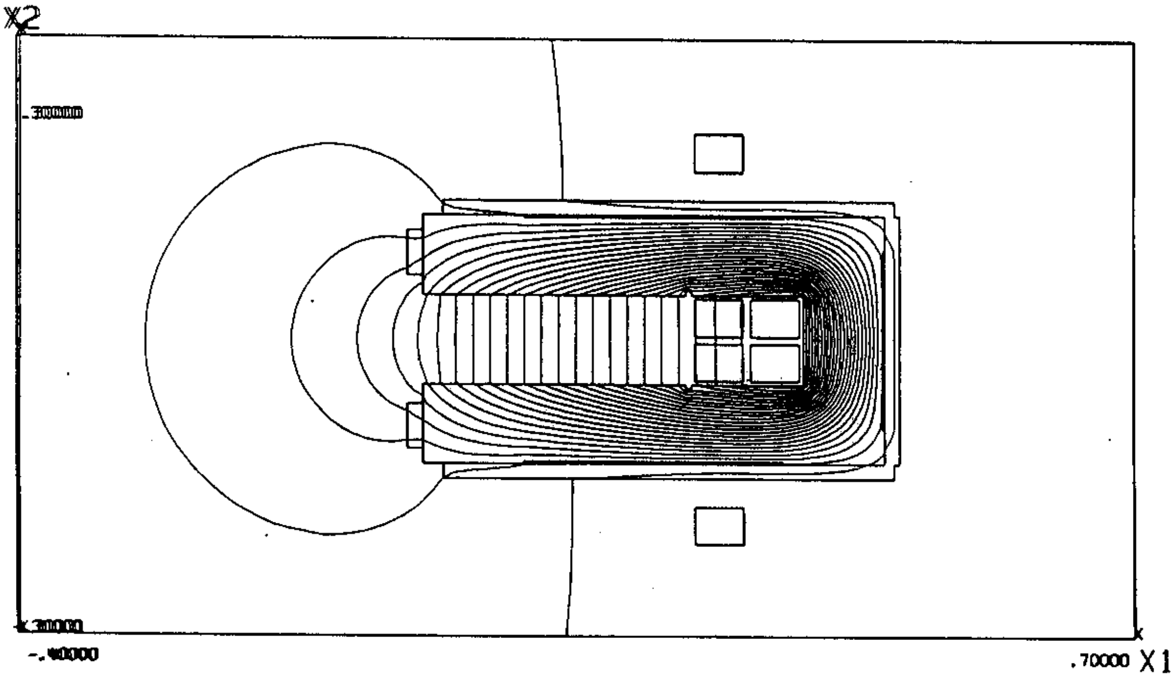

Fig. 3.3. Rotator dipole (typ BB)

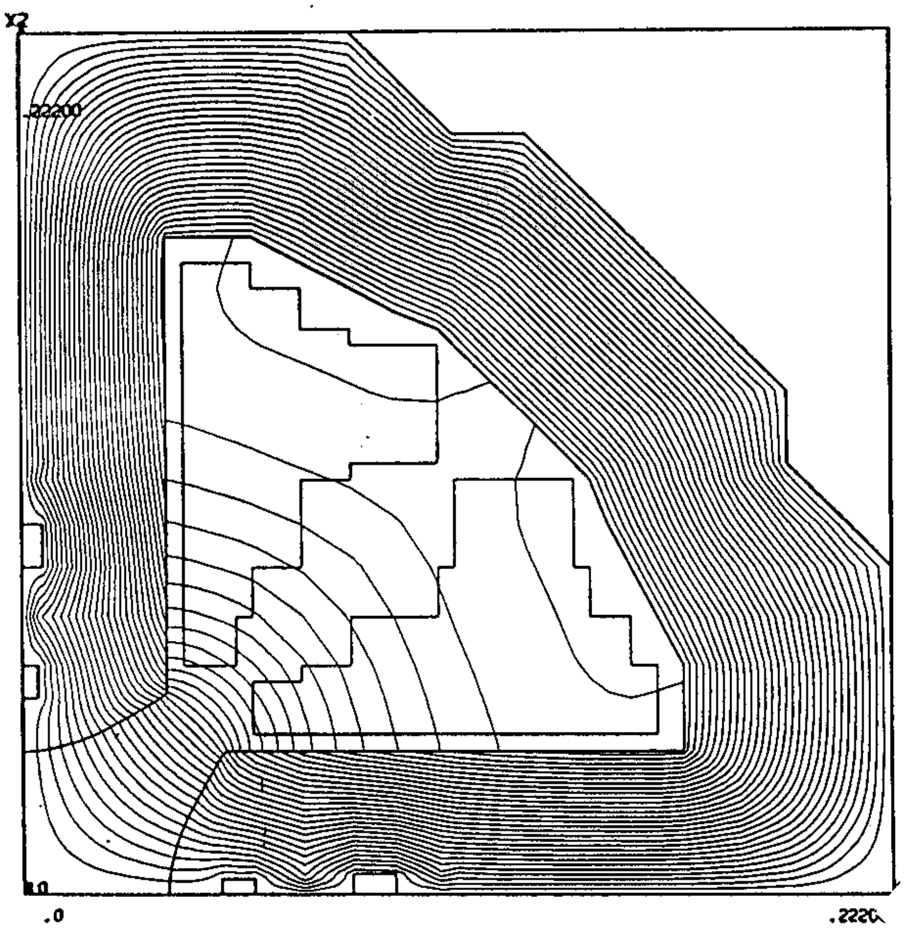

Fig. 3.4. Normal cell quadrupole (typ QE)

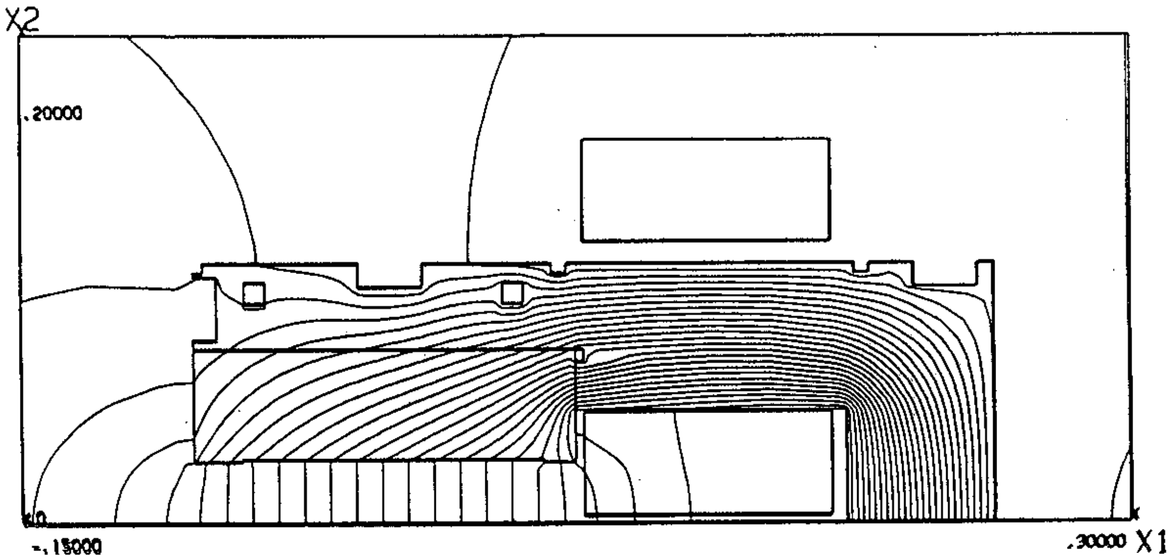

Fig. 3.5. Correction dipole (typ CH)

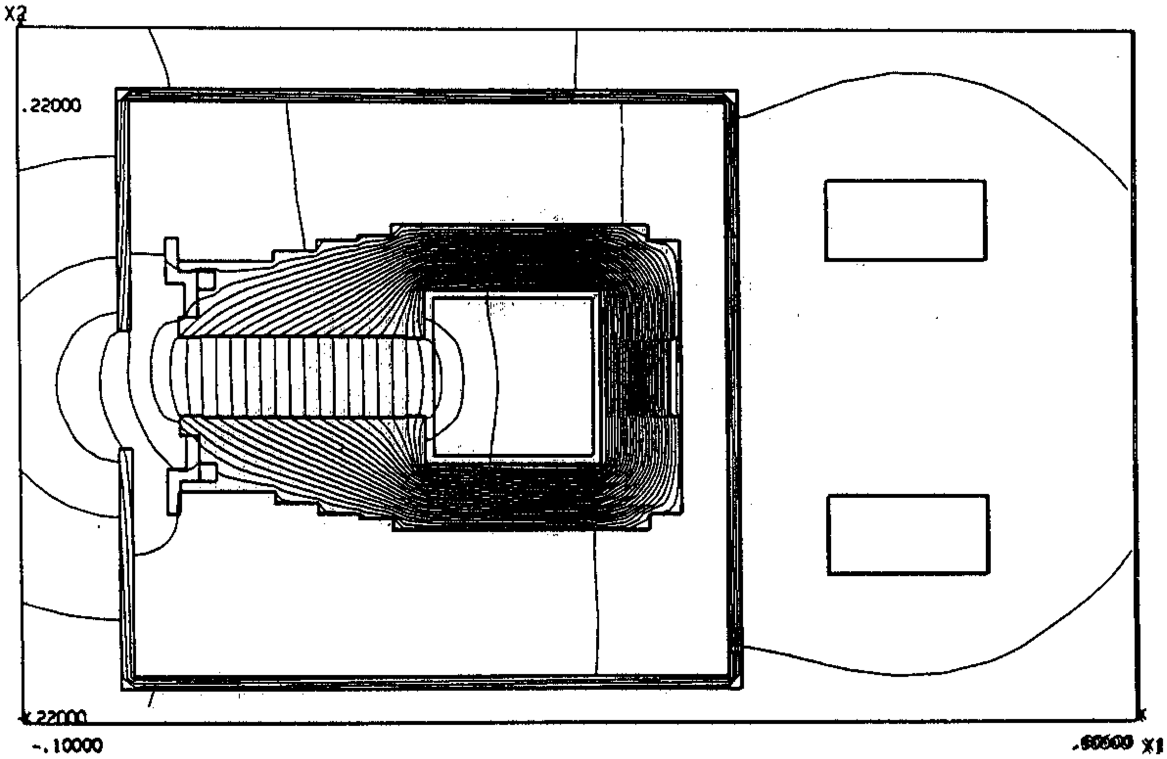

Fig. 3.6. HERA e^- arc bending magnet

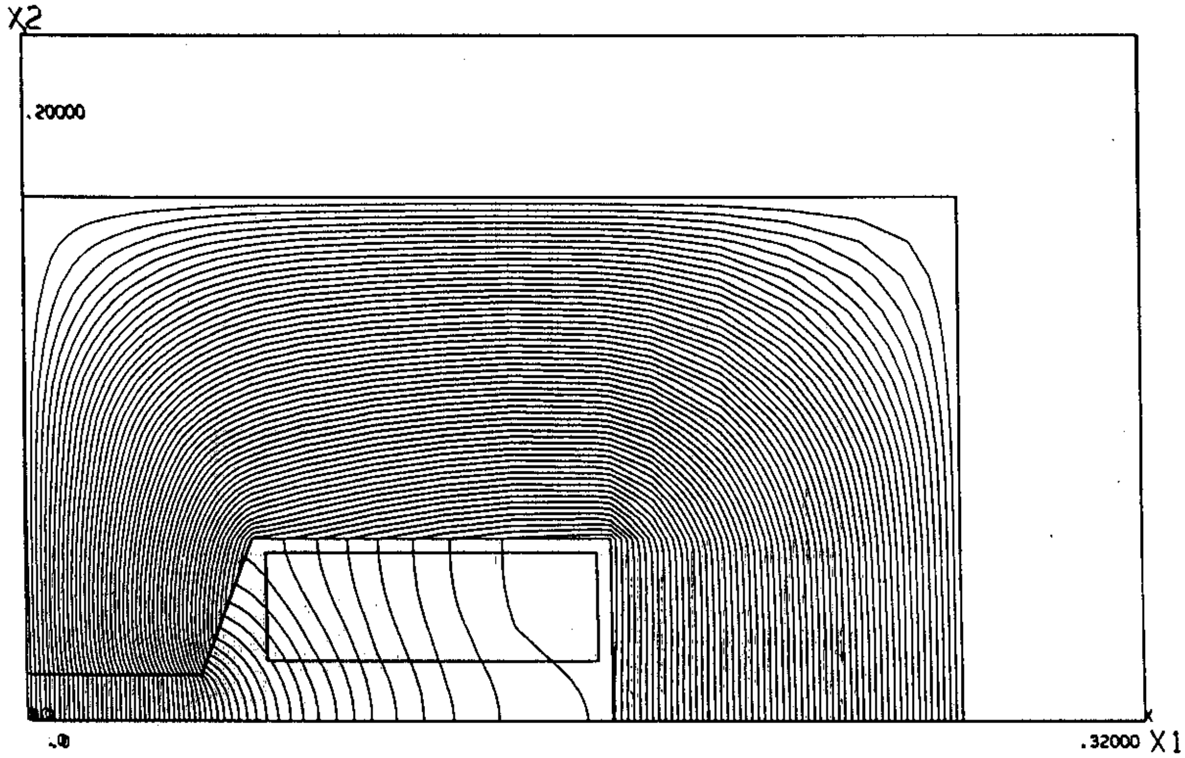

Fig. 3.7. HERA injection magnet

Appendix B contains job statistics of the presented problems.

Fig. 4.1 and 4.2 show plots generated by the mesh generator M3.

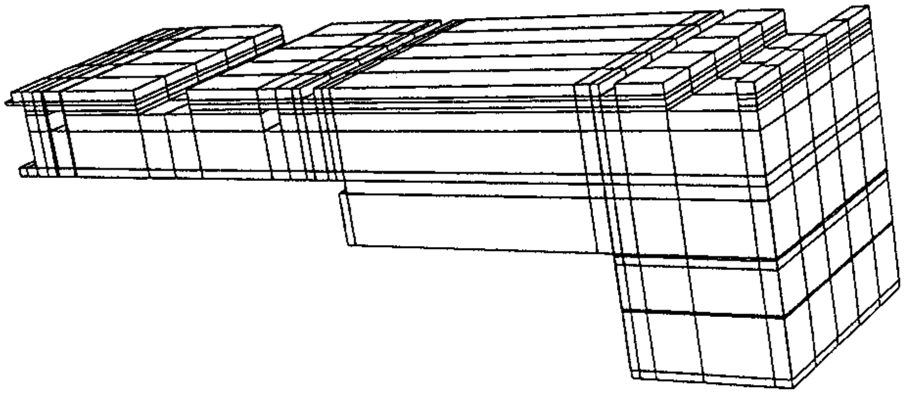

Fig 4.1. M3 plot of the basic generated mesh for the correction dipole

Fig. 4.1 is a 3D plot of the pole shown in fig. 3.5. The visible grid lines correspond to the basic mesh, which is necessary at the least to model the desired structure. Fig. 4.2 shows the magnet arrangement of the HERA e^- dipole and a sextupole. For symmetry reasons only the upper half of this arrangement was considered. This example was set up to study the end fields between the two magnets due to the current bus bars. The vacuum chamber is indicated. The coarse structure of the

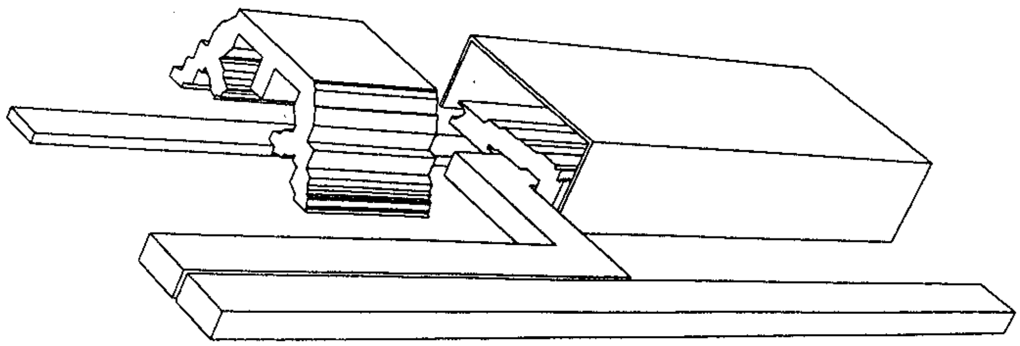

Fig.4.2. M3 plot of the HERA dipole and sextupole arrangement

sextupole is caused by the restriction of the number of grid lines. Attention must be paid as the grid lines of the dipole interfere with the structure of the sextupole and vice versa.

Some results produced by the postprocessor P3 are shown in fig. 5.1 to 5.5. For interpolation purposes P3 generates its own equidistant mesh, which is used in some plots and therefore is not identical with the PROFI mesh.

The arrow plot in fig. 5.1 represents the air gap field of the injection magnet (fig. 3.7) near the end region. The axial component of the magnetic field increases towards the pole tip marked by varying circle diameters. Fig. 5.3 to 5.5 show each component of the end field from the same magnet by isometric plots. The viewpoint and the selected field area for these plots are illustrated in fig. 5.2.

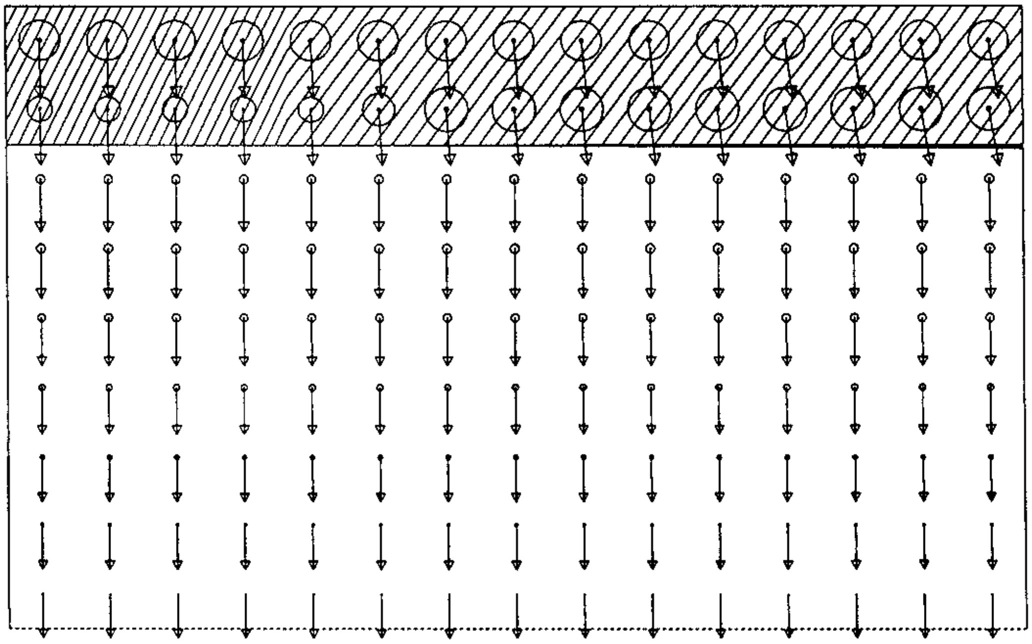

Fig. 5.1. P3 plot of the air gap field of the injection magnet near the end region

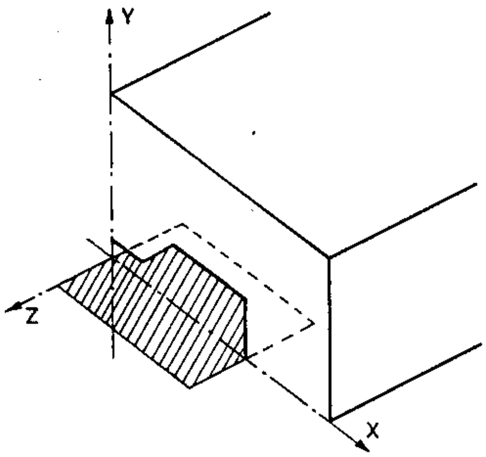

Fig. 5.2. Viewpoint

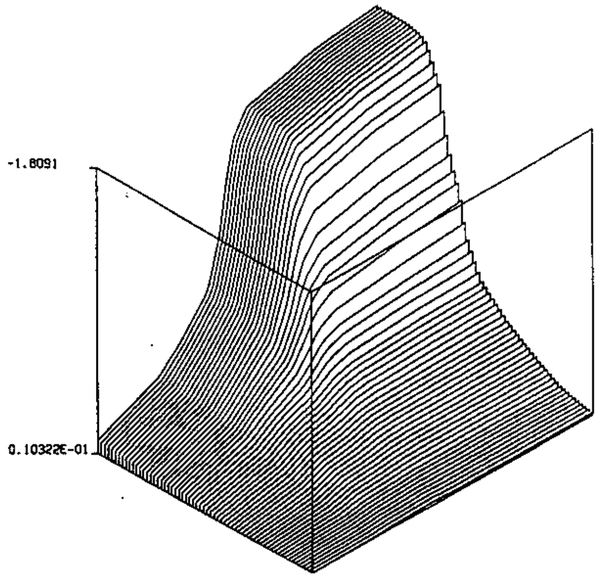

Fig. 5.3. B_y component

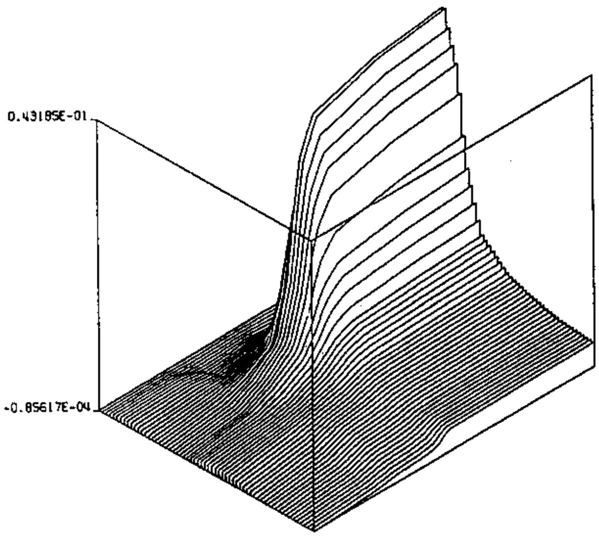

Fig. 5.4. B_x component

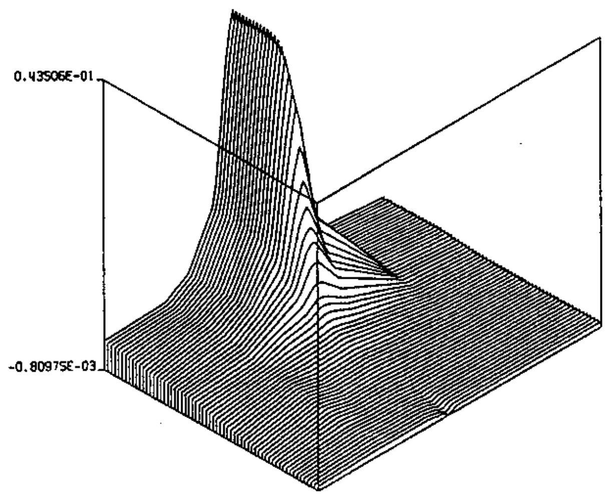

Fig. 5.5. B_z component

4. SABRINA

SABRINA is a three-dimensional interactive geometry-modeling program, which works with both combinatorial body geometry and MCNP (a Los Alamos Monte Carlo code for neutron and photon transport) surface geometry. For the geometry construction a set of simple geometric bodies are available:

- rectangular parallelpiped
- sphere
- right circular cylinder
- truncated right angle cone
- right angle wedge
- box
- arbitrary polyhedron.

Space is then described as the union or the intersection of these bodies. The user has to assign attributes to these combinations like transparencies, colours, colour intensities etc.. For a perspective display a spatial window and viewpoint must be specified. With a 3D cursor the geometry may be traced.

For input verification all specified bodies can be plotted in a line plot showing the intersection of all surfaces assuming transparent bodies. The resolution of the color plot is controlled by parameters for the pixel map and for the colour shading algorithm. An etched line plot works like a colour plot. It displays only the nontransparent cells and is the only method of displaying surfaces on a monochrome terminal.

Input control can be either from the user keyboard or from a local file thus allowing the processing of predefined command files.

The colour plot in fig. 6.1 shows a quarter of the correction dipole presented in fig. 3.5 and fig. 6.2 shows the complete end region of the injection magnet from fig. 3.7. The edges of the these figures have been intensified by etching the coloured plot, i. e. an etch plot has been drawn over the colour plot.

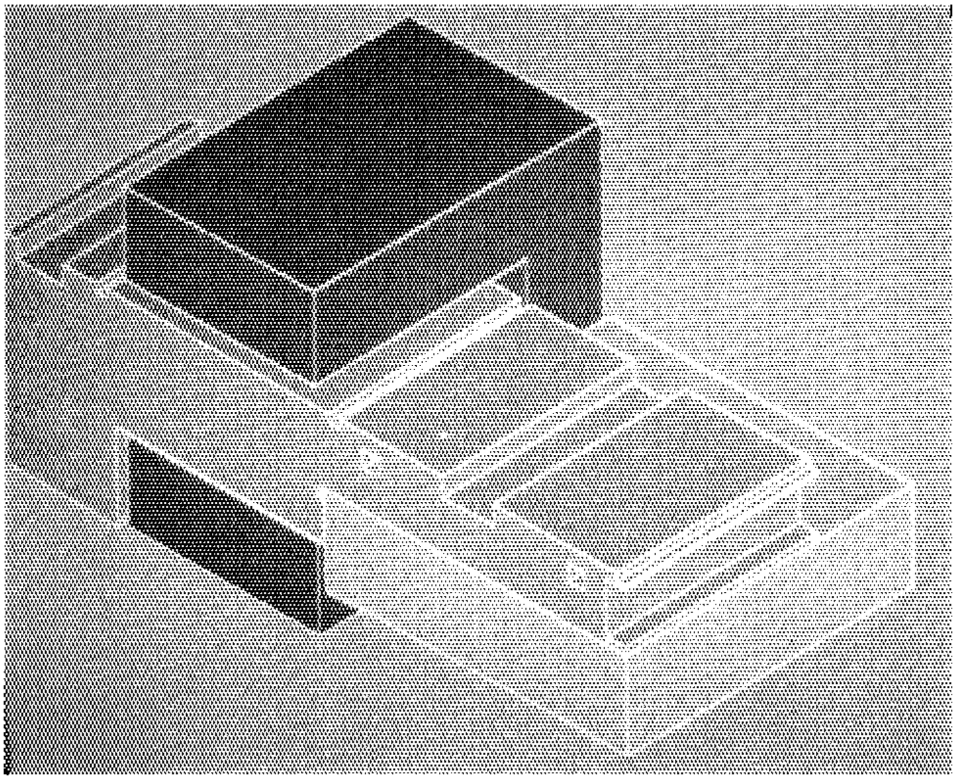

Fig. 6.1. Colour plot of the correction dipole

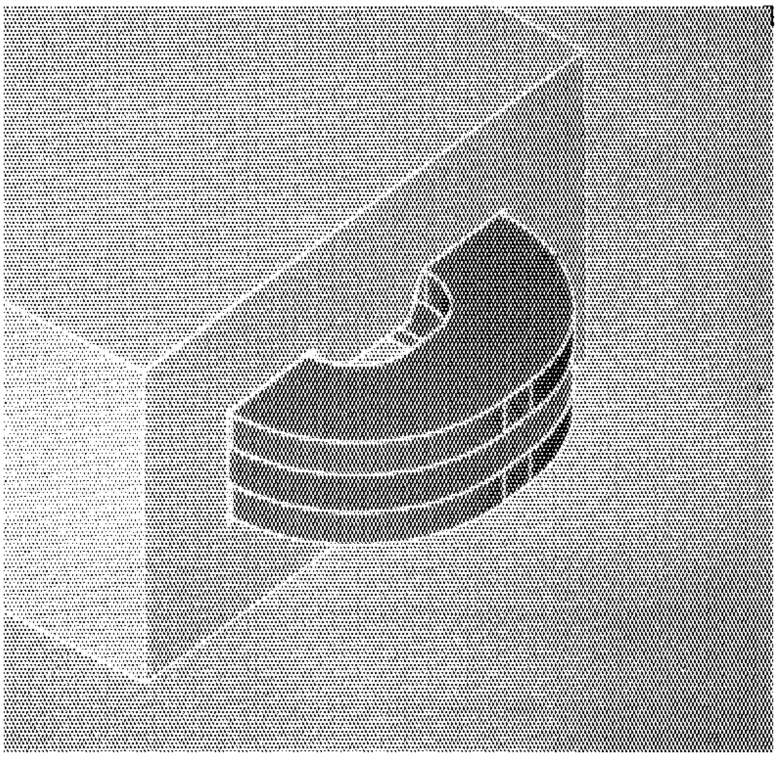

Fig. 6.2. End region of the injection magnet

5. PROFCOM

A major disadvantage of older PROFI versions is the very strict input format, e. g. the right alignment of integer numbers etc.. The estimation of the work array, region size, and file space, the set up of the FORTRAN program and the correct sequence of the subroutine calls as well as the creation of the appropriate JCL (understandable in its aesthetically restricted versatile complex simplicity only by the gods (or goddesses) of IBM, or their offspring [5]) led to the development of the preprocessor PROFCOM [7].

PROFCOM generates the necessary data, FORTRAN and JCL files. It accepts free format statements and uses versatile commands. Most key words are similar to the internal variable names within PROFI. For better readability long term key words may be chosen instead. In general the user need not to modify the generated code. He only has to submit the JCL file, which automatically includes the data and FORTRAN files.

According to the input logic of PROFI PROFCOM commands are grouped into several major headings:

- run description
- mesh description
- material definition
- material distribution
- current description
- iteration controls
- run controls.

In addition a new header has been added:

- job description.

Entries under this header pass information to the operating system, such as account number, job classes and priorities, file names etc..

In general the sequence of the headers and the commands is not important. Comment lines for legibility may be inserted everywhere. If the user specifies external files (e. g. for the checkpoint/restart facility), the presence of theses files is automatically checked.

Appendix C contains the PROFCOM input to a hypothetical current transformer. The material distribution shown in fig. C.1 has been chosen in such a way that all possible filling modes of an elementary cell supported by the MAFIA codes are used.

At present PROFCOM runs successfully for all magnetostatic calculations both with the vector potential and the scalar potential ansatz. It also should work for electrostatic, temperature and current distribution calculations.

6. Accuracy

The 3D calculations of the correction dipole (fig. 6.1) and the injection magnet (fig. 6.2) have been compared with extensive field measurements. The results for the correction dipole have been reported in [6]. One of the results, the vertical field versus the beam axis, is shown in fig. 8.1, the differences between the measured and calculated values may be taken from fig. 8.2. The position of the pole plate is indicated. In general it can be stated that for this problem the calculated values within the air gap almost agree with the measurements. Near the pole edges the difference is about 5%, and at the boundary about 1%. The latter deviation is caused by the boundary condition whereas the error at the pole edges result from a too coarse grid. The results of the deflection integral $\int B_y dz$ for an air gap/ pole length ratio of 0.17 are accurate to within 3%.

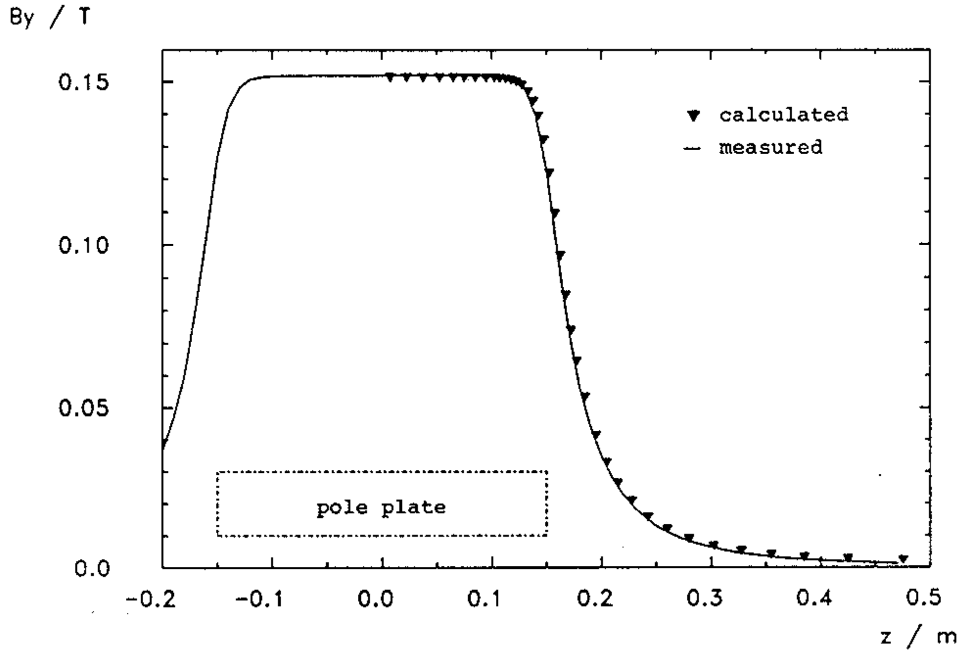

Fig. 8.1. Vertical field B_y along the beam axis

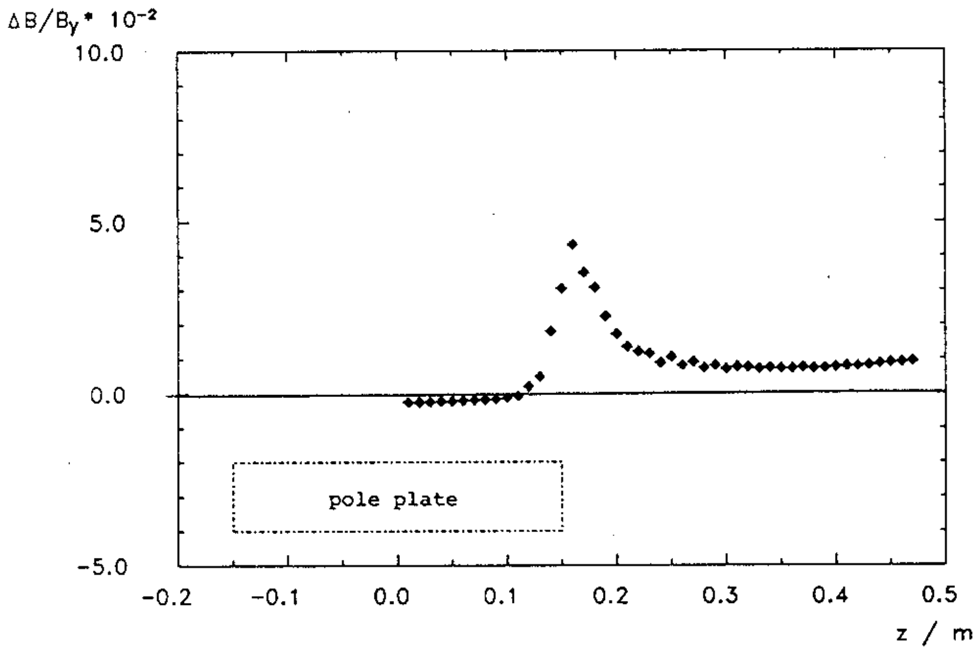

Fig. 8.2. Percentage variation of B_y

Similar measurements have been performed for the injection magnet. Fig. 8.3 shows the field distribution at the end region of this magnet. The accuracy depends on the same criteria explained in the previous example. Additionally the exciting current during the measurements slightly differs from the one used in calculations. The deflection integral has been measured with a moving coil, the difference is less than 0.6 % (the air gap/ pole length ratio is 0.0051). To obtain information about the field quality the distribution across the median plane has been compared. Fig. 8.4 and 8.5 show the results at a shimmed and no-shimmed position at beam level. The orientation of the vaccuum chamber is also indicated. Note that the measurements have been performed through the whole air gap whereas the calculations have been carried out only for half of it due to symmetries (straight magnet assumed!). The measured values in fig. 8.5 are not correctly centered.

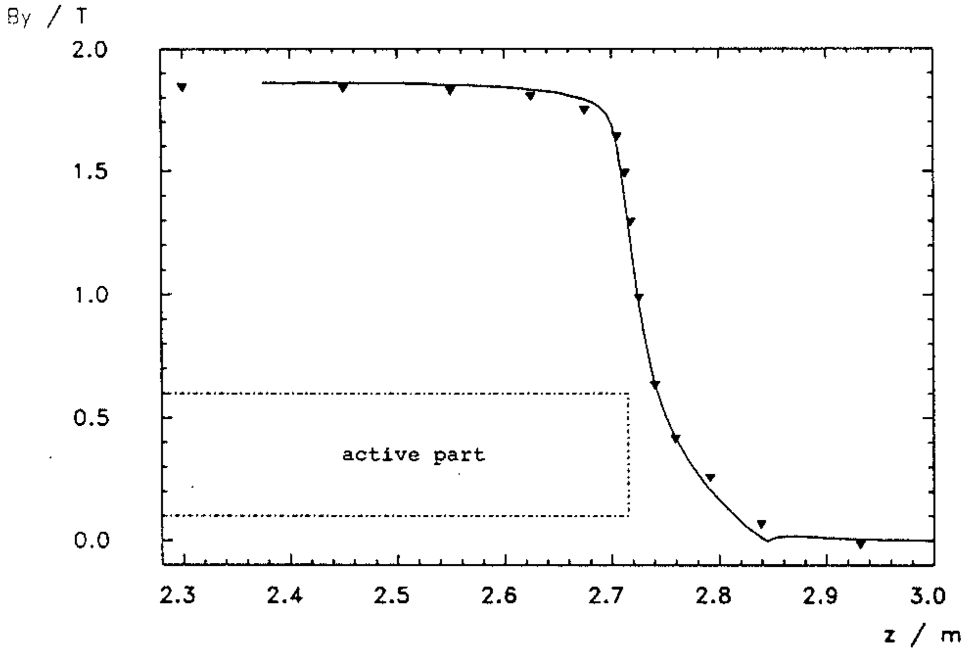

Fig. 8.3. B_y vs. beam axis of the injection magnet

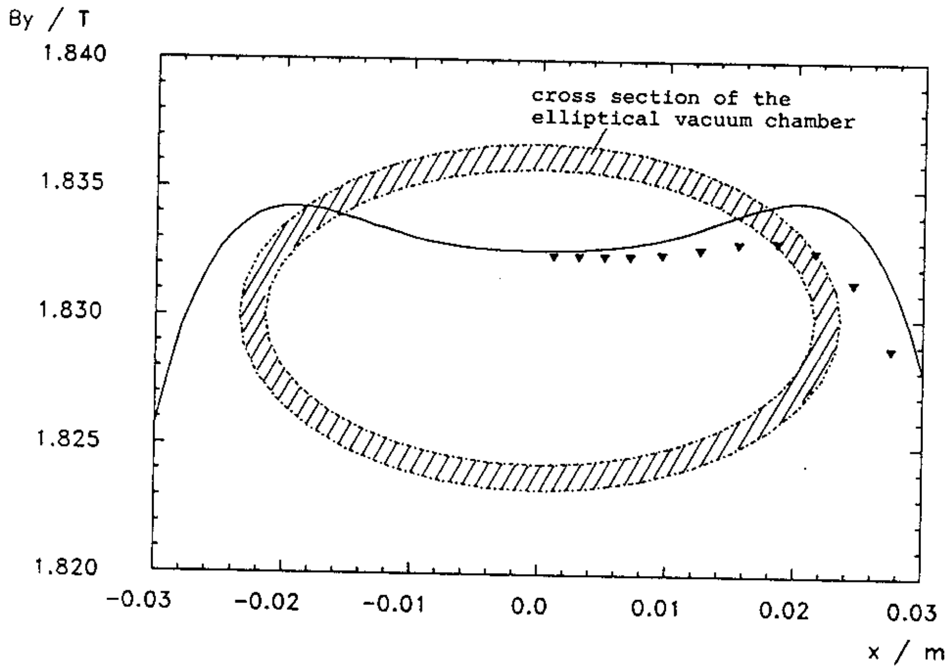

Fig. 8.4. Vertical field at no-shimmed position

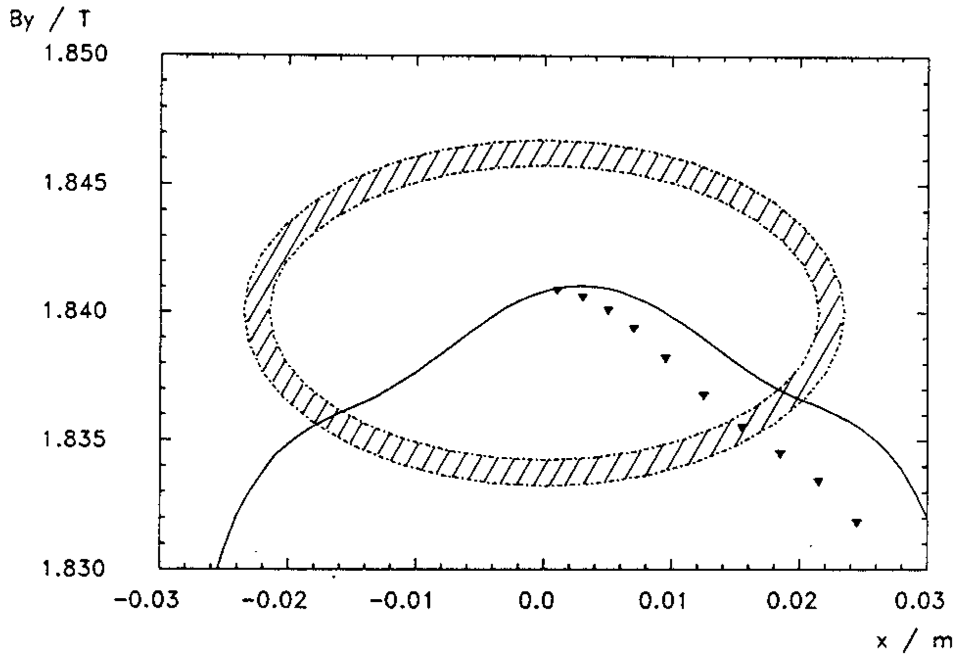

Fig. 8.5. Vertical field at shimmed position

7. Acknowledgement

The author wishes to acknowledge the helpful discussions of all colleagues who are involved in the presented examples. In particular he wishes to thank J. Parker, G. Rodenz, H. Mais, and D. Barber for their suggestions and careful reading the manuscript.

8. References

[1] W. Mueller, J. Krueger, A. Jacobus, R. Winz, T. Weiland, H. Euler, U. Hamm, W.-R. Novender: Numerical Solution of 2- or 3-Dimensional Nonlinear Field Problems by Means of the Computer Program PROFI
Archiv fuer Elektrotechnik 65 (1982), 299-307

[2] T. C. Barts, M. J. Browman, R. Cooper, C. T. Mottershead, G. Rodenz, S. G. Wipf, B. Steffen, R. Klatt, F. Krawczyk, W.-R. Novender, C. Palm, T. Weiland: MAFIA - A Three Dimensional Electromagnetic CAD System for Magnets, RF Structures, and Transient Wake-Field Calculations
Proceedings of the 1986 Linear Accelerator Conference, SLAC, 1986,

[3] James T. West III: SABRINA - An Interactive Three-Dimensional Geometry-Modeling Program for MNCP
LA-10688, UC-32, Oct. 86, Los Alamos National Laboratory

[4] W.-R. Novender, W. Mueller: 3-Dimensional Nonlinear Calculations of Magnetic Fields in Turbogenerators
IEEE Transactions on Magnetics, Vol. MAG-19, No. 6, November 1983 2604-2607

[5] cited from the distribution letter for the SCEPTRE program (IBM version) from Brent White, SCEPTRE Project Officer, AFWL Kirtland

[6] U. Berghaus, W.-R. Novender: Three Dimensional Magnet Mapping and Calculations for the Prototype of the HERA Correction Dipoles
DESY M-86-09, October 1986 (in German)

The accuracy of the outer cycles is controlled from two successive outer cycles m and (m+1) by the variable DMUEQU

$$DMUEQU = \frac{1}{Ne} \sum_{j=1}^{Ne} \left| \frac{\mu_j^{(m+1)} - \mu_j^{(m)}}{\mu_j^{(m+1)}} \right|$$

with Ne as the count of all iron filled mesh cells. In practise a value of 0.01 < DMUEQU < 0.001 is sufficient. If this condition is satisfied the last outer cycle is performed.

The accuracy of the SOR iteration is similarly controlled. The variable Rn is called the residuum and is defined at the $(n+1)^{th}$ inner cycle as

$$Rn = \sum_{i=1}^{N} \left| x_i^{(n+1)} - x_i^{(n)} \right|$$

where N denotes the number of mesh points, **x** the solution vector. The iteration stops as soon as the condition Rn/Rl < EBSI is fullfilled. Values of 0.1 < EBSI < 0.05 are recommended, for the last outer cycle EBSI should be less than 10^{-6} in order to get an almost source free field.

The typical convergence behaviour of the outer cycle is depicted in fig. A.2, the plot of the residuum Rn and the listing of the iteration statistics are shown in fig. A.3 and A.4. After every 7th outer cycle an iteration "accelerator" technique has been invoked (marked by the letter "G" in the column "TYP" of the iteration statistic), which causes a temporary divergence of DMUEQU and Rn.

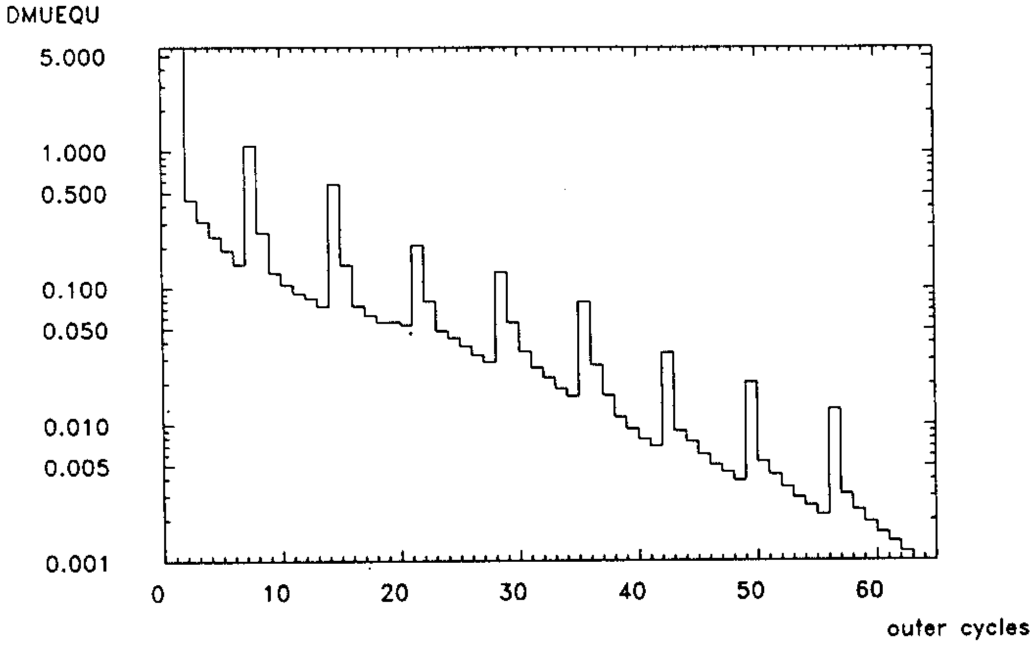

Fig. A.2: Convergence of the outer cycles

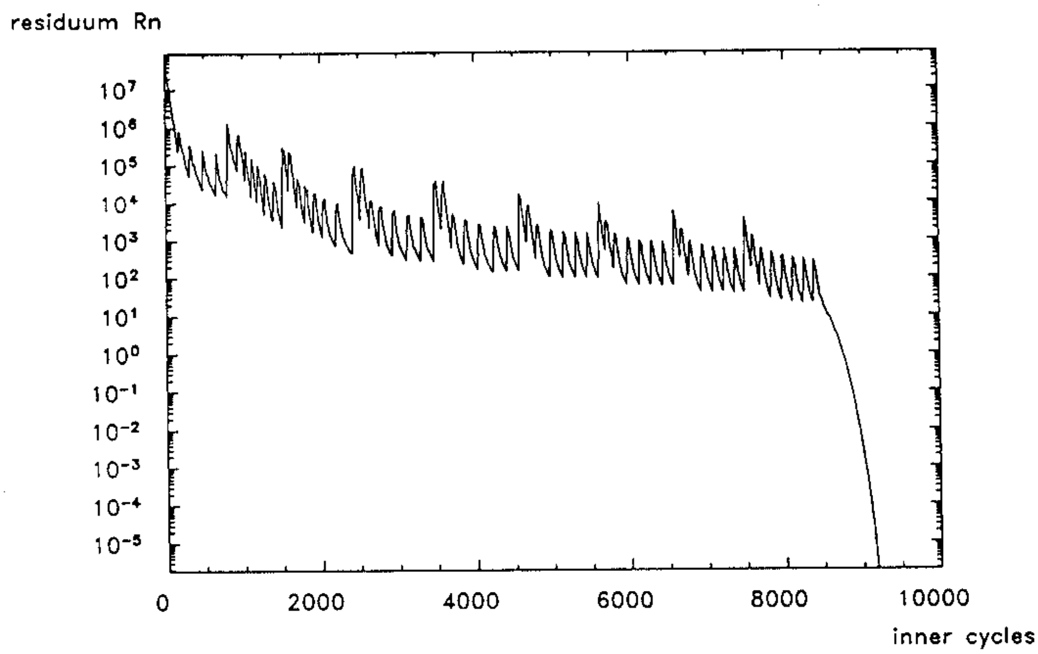

Fig. A.3: Convergence of the inner cycles

609 10@2200A,BLECH 0.1X500,GAP 13.9 21/05/87

------------------------- I T E R A T I O N SUMMARY -------------------------

# OUT CYCLCES	# INN CYCLCES	TYP	START OMEGA	END OMEGA	LAST X VALUE	START RESIDUUM	END RESIDUUM	DPHIQU	DPHIMAX	DMUEQU	DMUEMAX	TIME <SEC>
1	60		1.9513	1.9513	8.61277D+03	8.92718D+07	5.07464D+06	3.30756D+03	1.34562D+04	5.83100D+00	1.83292D+01	106.11
2	80		1.9513	1.9513	1.16940D+04	3.57264D+06	2.38366D+05	1.74653D+03	7.47557D+03	4.44535D-01	1.13084D+01	45.46
3	130		1.9513	1.9513	1.33614D+04	8.03801D+05	4.99448D+04	6.93273D+02	2.74304D+03	3.11458D-01	1.59913D+00	67.41
4	160		1.9513	1.9513	1.42156D+04	3.57064D+05	2.23470D+04	3.31786D+02	1.25236D+03	2.40314D-01	8.30999D-01	81.06
5	160		1.9513	1.9513	1.46896D+04	2.59205D+05	1.65944D+04	1.79663D+02	6.64827D+02	1.89316D-01	5.14912D-01	81.22
6	140		1.9513	1.9513	1.49701D+04	2.25955D+05	1.46059D+04	1.05207D+02	3.86459D+02	1.49926D-01	3.65507D-01	71.74
7	120	G	1.9513	1.9513	1.32963D+03	1.29078D+06	7.39319D+04	6.35067D+02	2.72833D+03	1.10584D+00	1.02514D+01	68.34
8	90		1.9513	1.9513	1.53734D+04	5.75958D+05	4.00554D+04	4.74323D+02	2.08850D+03	2.57988D-01	4.27677D+00	49.68
9	70		1.9513	1.9513	1.54612D+04	2.51754D+05	1.48401D+04	4.92247D+01	3.09599D+02	1.30069D-01	1.57659D+00	40.79
10	70		1.9513	1.9513	1.55520D+04	1.53527D+05	1.07016D+04	3.57846D+01	1.98122D+02	1.05994D-01	5.56382D-01	40.82
11	80		1.9513	1.9513	1.56240D+04	9.71669D+04	4.99613D+03	2.64303D+01	1.39512D+02	9.14680D-02	3.83671D-01	45.12
12	100		1.9513	1.9513	1.56840D+04	6.02510D+04	3.42323D+03	2.08863D+01	1.01741D+02	8.44639D-02	3.42082D-01	53.83
13	110		1.9513	1.9513	1.57307D+04	3.86444D+04	2.23301D+03	1.57519D+01	7.27311D+01	7.38974D-02	2.71774D-01	58.31
14	70	G	1.9513	1.9513	1.61652D+02	3.02278D+05	2.08837D+04	4.64632D+01	2.80237D+02	5.80779D-01	5.71912D+00	46.07
15	100		1.9513	1.9513	1.57689D+04	1.35852D+05	7.65573D+03	4.00967D+01	2.78490D+02	1.49023D-01	3.84716D+00	53.73
16	90		1.9513	1.9513	1.58022D+04	4.55138D+04	2.98876D+03	1.00191D+01	5.96690D+01	7.43186D-02	9.51452D-01	49.37
17	100		1.9513	1.9513	1.58270D+04	2.86993D+04	1.63516D+03	8.67408D+00	4.00428D+01	6.30636D-02	3.23142D-01	54.18
18	110		1.9513	1.9513	1.58469D+04	1.73398D+04	1.20038D+03	7.23647D+00	2.96824D+01	5.59922D-02	2.96273D-01	59.29
19	160		1.9513	1.9513	1.58657D+04	1.05937D+04	6.96137D+02	6.98457D+00	2.52689D+01	5.66267D-02	2.87674D-01	80.61
20	210		1.9513	1.9592	1.58829D+04	6.49714D+03	4.36223D+02	6.30362D+00	2.38654D+01	5.38652D-02	2.77419D-01	102.07
21	90	G	1.9513	1.9513	3.97752D+01	5.75649D+04	3.53828D+03	1.23313D+01	1.24751D+02	2.08885D-01	2.89793D+00	55.09
22	110		1.9513	1.9513	1.58940D+04	3.08538D+04	2.11027D+03	9.46438D+00	9.07393D+01	8.04081D-02	2.19122D+00	58.41
23	110		1.9513	1.9513	1.59046D+04	1.07919D+04	7.01617D+02	4.02727D+00	1.95098D+01	4.85892D-02	5.70527D-01	58.14
24	160		1.9513	1.9513	1.59161D+04	5.79769D+03	3.87178D+02	3.90874D+00	1.69716D+01	4.30519D-02	3.66362D-01	80.02
25	180		1.9513	1.9513	1.59262D+04	4.38696D+03	2.83914D+02	3.38115D+00	1.47555D+01	3.74539D-02	2.64297D-01	88.83
26	170		1.9513	1.9513	1.59344D+04	4.03256D+03	2.75320D+02	2.79099D+00	1.24765D+01	3.24377D-02	2.19129D-01	84.30
27	160		1.9513	1.9513	1.59411D+04	4.14839D+03	2.75036D+02	2.34504D+00	1.07306D+01	2.87107D-02	2.06270D-01	79.63
								1.19043D-01	9.58640D-01	1.61490D-03	4.83928D-02	66.10
61	130		1.9513	1.9513	1.60074D+04	3.19983D+02	1.98056D+01	1.05165D-01	8.57325D-01	1.38380D-03	3.61496D-02	66.15
62	120		1.9513	1.9513	1.60077D+04	3.02012D+02	2.07856D+01	8.90389D-02	7.35990D-01	1.16411D-03	2.74087D-02	61.84
63	800		1.9513	1.9704	1.60082D+04	2.78712D+02	1.87413D-06	1.20110D-01	9.84689D-01	1.16411D-03	2.74087D-02	357.41

———————— ENDE DES P R O F I - LAUFES ————————

ZEITVERBRAUCH (SEC):

VORBEREITUNG	10.64
SYSTEM	4479.24
AUSWERTUNG	3.80
GESAMT	4493.68

ANZAHL DER MELDUNGEN:

0 WARNUNGEN
0 FEHLER

Fig. A.4: Iteration statistic (extract)

10. Appendix B: Job statistics of the presented examples

2D calculations

Fig. No.	problem	mesh-points	outer cycles	DMUEQU	EBSI **)	CPU [sec]	typ *)
3.4	quadrupole QE	5329	48	<0.0026	$< 10^{-6}$	760	VP
3.6	e-dipole	7776	31	<0.0012	$< 10^{-6}$	1150	
3.2	wake field experim.	27234	4	<0.0009	$< 10^{-8}$	480	VP
3.5	correction dipole	5115	12	<0.0003	$< 10^{-7}$	640	
3.1	bending magnet	2898	8	<0.0004	$< 10^{-7}$	40	
3.3	rotator dipole H2	5074	13	<0.0006	$< 10^{-8}$	175	
3.7	injection magnet	2444	40	<0.0028	$< 10^{-8}$	170	

3D calculations

Fig. No.	problem	mesh-points	outer cycles	DMUEQU	EBSI **)	CPU [sec]
6.1	correction dipole	26320	17	<0.0019	$< 10^{-8}$	1990
		51324	21	<0.0073	$< 10^{-8}$	5660
6.2	injection magnet	23100	62	<0.0008	$< 10^{-8}$	2030
		42000	63	<0.0012	$< 10^{-8}$	4480
C.1	current transformer	6800	6	<0.0008	$< 10^{-8}$	145

*) VP=solution via vector potential

**) used for the last outer cycle

The CPU time corresponds to an IBM 3084Q 48-48 processor.

Note: The number of outer cycles and the stated CPU time strongly depend on saturation effects. Therefore the number of mesh points and the solution time should be compared carefully.

11. Appendix C: PROFCOM example

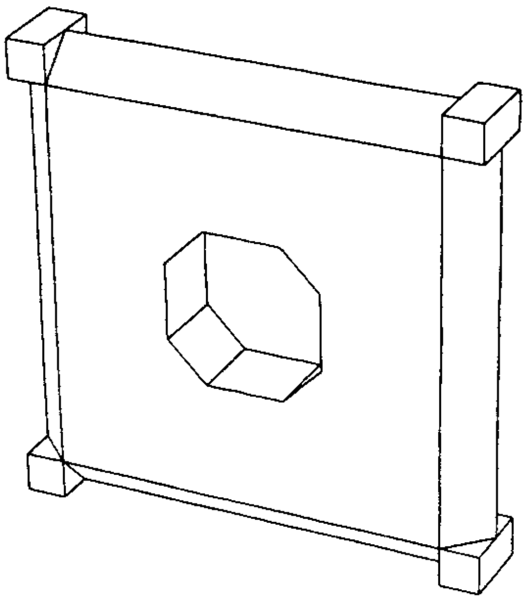

Fig. C.1: Material distribution of an hypothetical current transformer.

```
JOB-DESCRIPTION
  ACCOUNT=' [illegible] ',CLASS='K',TIME=180,PRIORITY='HIGH'
  DA-DSN='MPYNOV.P.DA010'
  RUN-NUMBER=10,TITLE=' 3D EXAMPLE, SHOWING ALL AVAILABLE FILLING MODES'
RUN-DESCRIPTION
  PROBLEM-TYPE=1,COORDINATE-SYSTEM=4,BOUNDARY-CONDITIONS=2,2,2,2,2,2
MESH-DESCRIPTION
  X1-SCALEFACTOR=1E-3, X2-SCALEFACTOR=1E-3, X3-SCALEFACTOR=1E-3
  X1=-1000 -800 -600 -500 -400 -300 -200 -100 -50 -25
      1000  800  600  500  400  300  200  100  50  25
  X2=-1000 -800 -600 -500 -400 -300 -200 -100 -50 -25
      1000  800  600  500  400  300  200  100  50  25
  X3=-1000 -800 -600 -500 -400 -300 -200 -100   0
      1000  800  600  500  400  300  200  100
```

Fig. C.2. PROFCOM input listing (part 1)

```
MATERIAL-DEFINITION
  NUMBER=1,TYPE=1,INITIAL-VALUE=300,LAMINATION-FACTOR=1,1,0.98
* MKL:ST37
       FUNCTION
     0.        0.
     37.5      0.2
     85.       0.4
     150.      0.6
     245.      0.8
     395.      1.
     625.      1.2
     1060.     1.4
     1500.     1.5
     2500.     1.555
     5000.     1.67
     10000.    1.78
     20000.    1.93
     30000.    2.03
  NUMBER=2,TYPE=1,INITIAL-VALUE=300,LAMINATION-FACTOR=1,1,0.98 MUMA=1
  NUMBER=3,TYPE=1,INITIAL-VALUE=300,LAMINATION-FACTOR=1,1,1     MUMA=1
  NUMBER=4,TYPE=1,INITIAL-VALUE=300,LAMINATION-FACTOR=1,1,1     MUMA=1
MATERIAL-DISTRIBUTION
  SHAPE=0,DIMENSIONS=-500  500 -500  500 -100 100 MAZI=3
  SHAPE=0,DIMENSIONS=-200  200 -200  200 -100 100
  SHAPE=0,DIMENSIONS=-500  500  500  600    0 100 MAZI=3  MAFU=10
  SHAPE=0,DIMENSIONS=-500  500  500  600 -100   0 MAZI=3  MAFU=11
  SHAPE=0,DIMENSIONS=-500  500 -600 -500    0 100 MAZI=3  MAFU=12
  SHAPE=0,DIMENSIONS=-500  500 -600 -500 -100   0 MAZI=3  MAFU= 9
  SHAPE=0,DIMENSIONS=-200 -100  100  200 -100 100 MAZI=3  MAFU= 4
  SHAPE=0,DIMENSIONS=-200 -100 -200 -100 -100 100 MAZI=3  MAFU= 2
  SHAPE=0,DIMENSIONS= 100  200  100  200 -100 100 MAZI=3  MAFU= 1
  SHAPE=0,DIMENSIONS= 100  200 -200 -100 -100 100 MAZI=3  MAFU= 3
  SHAPE=0,DIMENSIONS= 500  600 -500  500    0 100 MAZI=3  MAFU= 6
  SHAPE=0,DIMENSIONS= 500  600 -500  500 -100   0 MAZI=3  MAFU= 8
  SHAPE=0,DIMENSIONS=-600 -500 -500  500    0 100 MAZI=3  MAFU= 7
  SHAPE=0,DIMENSIONS=-600 -500 -500  500 -100   0 MAZI=3  MAFU= 5
  SHAPE=0,DIMENSIONS=-600 -500 -600 -500 -100 100 MAZI=4
  SHAPE=0,DIMENSIONS= 500  600 -600 -500 -100 100 MAZI=4
  SHAPE=0,DIMENSIONS=-600 -500  500  600 -100 100 MAZI=4
  SHAPE=0,DIMENSIONS= 500  600  500  600 -100 100 MAZI=4

CURRENT-DESCRIPTION
  CURRENT=500,FILAMENT
     0    0    -700
     0    0     700
     0  700     700
     0  700    -700
     0    0    -700
ITERATION-CONTROLS
  MODE='BSOR', MAXIMUM_OUTER_CYCLES=17, LAST_OUTER_CYCLE=1, DMUEQU=3E-3
  OUTER-CYCLE=1, MAXIMUM_INNER_CYCLES=170, RESIDUUM=0.07
      OMEGA-CALCULATION=100
  OUTER-CYCLE=99, MAXIMUM_INNER_CYCLES=3700, RESIDUUM=1E-8
RUN-CONTROLS
  ITERATE ' '
  PRINT='HI1 ',PRINT-FORMAT=77
  PRINT='HI2 ',PRINT-FORMAT=77
  PRINT='HI3 ',PRINT-FORMAT=77
END

-- END OF DATA ENCOUNTERED --

==> WARNING: FILE "MPYNOV.P.DA010                             " DOES NOT EXIST!
```

Fig. C.2. PROFCOM input listing (continued)