Lecture 4

POISSON
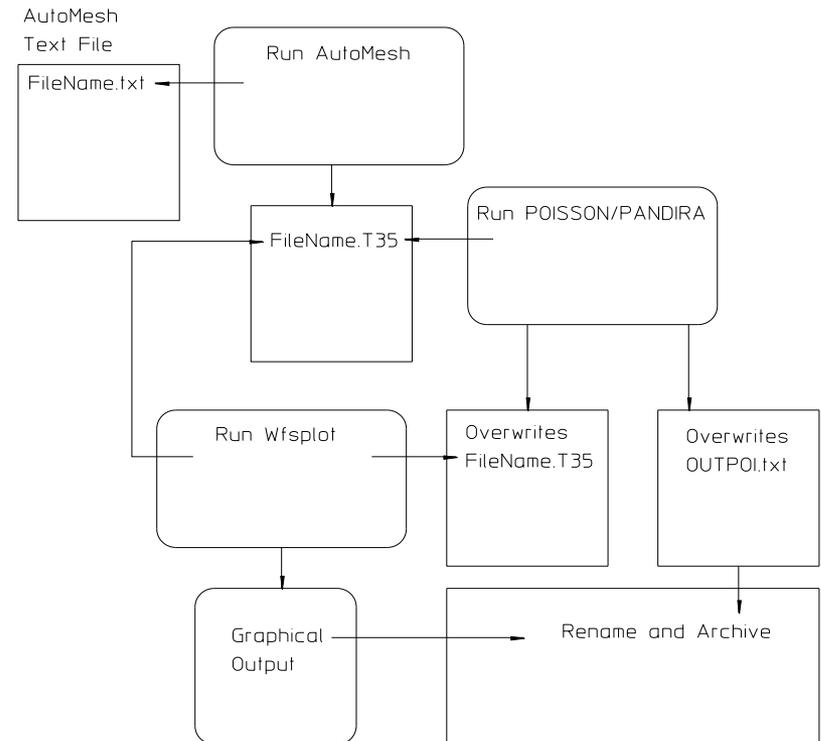## A Two-Dimensional
Magnetostatic Solver

POISSON

- POISSON/SUPERFISH are a family of electric and electromagnetic codes, written originally by Klaus Halbach and Ron Holsinger.

  - Information regarding the code family and means of downloading the codes can be obtained by contacting James H. Billen <jbillen@lanl.gov>

- It is a public access code (it's *free*), maintained under contract with DOE by Los Alamos National Accelerator Laboratory (LANL) personnel.

- The LANL interest is mainly in the RF field, so the bulk of the development and maintenance of this family of codes is in the SUPERFISH area. Thus, maintenance and development of the magnetostatic capabilities is limited by funding and time.

Magnetostatic Elements

- Four main code components are of interest to those involved in magnet design.
  - Automesh.EXE
    - Automesh is a automatic mesh generator. It takes input information written in a text file and generates a mesh of points written in several matrices used by POISSON or PANDIRA to solve the distribution of magnetic fields in a two dimensional magnet cross section.
  - poisson.EXE
    - POISSON uses the Automesh output and solves for the vector potential distribution in the two dimensional geometry by successive approximation using the relaxation method. It computes the field distribution from the vector potential distribution.
  - pandira.EXE
    - PANDIRA solves for the vector potential by diagonalizing the matrix.
  - Wfsplot.EXE
    - WFSPLOT is a graphics routine which can present either the lattice geometry from Automesh or the Vector equi-potentials resulting from POISSON or PANDIRA solutions.

Program Flow Chart

- The structure of the information flow for the POISSON/Pandira program group is shown in the diagram.
- A text file is written which includes all the information required to define the problem.
  - If WFSPlot is run alt this point, the Tape35 file is used to graphically present the geometry information.
- AutoMesh is run using this file. Automesh overwrites the current Tape35 file.
- Poisson/Pandira is run using the current Tape35 file and overwrites the Tape35 file writeen by AutoMesh.
  - WFSPlot is run using the current Tape35 file and creates a graphical output of the calculated results.
- Outpoi is a text file which is overwritten each time POISSON or Pandira is run.
- This file contains the information used in the program, including the BH curve called in the .txt file.
- Parts of this file (the results of the edit) can be copied and used to present the results of the calculations.

AutoMesh Text File

FileName.txt

Run AutoMesh

FileName.T35

Run POISSON/PANDIRA

Run Wfsplot

Overwrites FileName.T35

Overwrites OUTPOI.txt

Graphical Output

Rename and Archive

Text File

A portion of a text file written for a dipole geometry is shown. The first two lines of the file are title lines which are carried throughout the calculations. All the lines shown are preceded by a ! sign, which indicates that these are comments.

Sample Problem
Simple Dipole
!First two lines in the text file are the title and descriptors for the problem.
!These titles will be carried in subsequent output files.
!mat=1 means air region, =2 means iron region using the internal iron BH properties.
!kprob=0 means POISSON problem
!mode=0 means finite permeability using one of the tables
!xmin, xmax, ymin, ymax are the physical horizontal and vertical limits of the problem.
! xreg1 and kreg1 are the x value for the mesh with kreg1 nodes. kmax is the no. of k
!nodes. More regions defined by xreg2, kreg2, etc. are possible.
! yreg1 and lreg1 are the y value for the mesh with lreg1 nodes. lmax is the no. of l nodes.
! icylin=0 is Cartesian Coordinates, =1 is cylindrical coordinates.
! xminf, xmaxf, yminf, ymaxf are the physical limits for the data output limits. ktop and
!ltop are the number of data output points over the limits. Example, xminf=-30,
!xmaxf=30, ktop=13 means that the output edit data will have 13 entries from -30 to +30
!mm at 5 mm. increments. ienergy=1 means that the stored energy will be computed.
! nbsup, nrslo, nbsrt, nbslf are boundary condition for UPper, LOwer, RTside, LFside.
! =0 and 1 mean Dirichlet and Neumann Boundaries, respectively.
! conv=1 is the default for cm. =.1 is for mm, =2.54 is for inches.
! The following are the CONS for the harmonic analysis.
! ktype=124. First integer =1 dipole, 2 quadrupole.
!Second integer =2 means multipole inteval. Third integer =1 means midplane
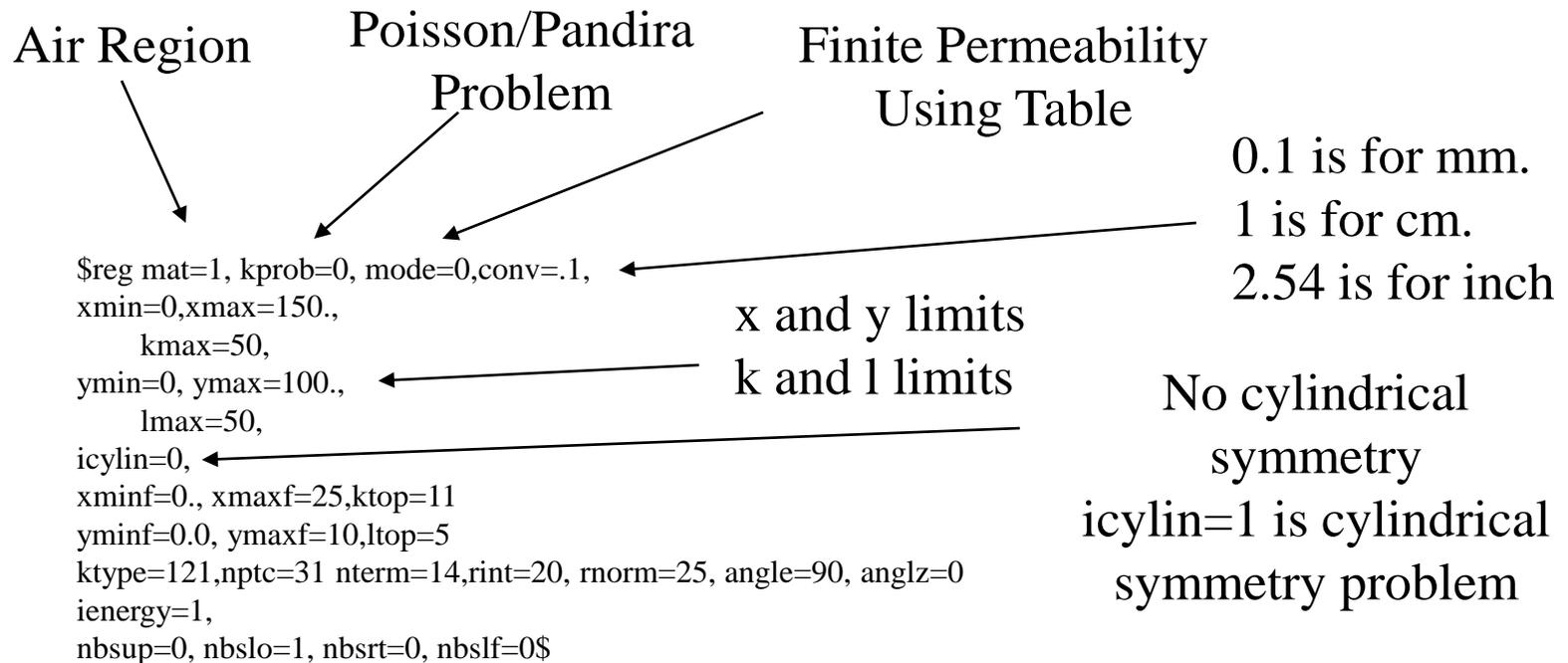!symmetry, =0 skew terms.
! nptc=30 number of arc points, nterm=number of terms, rint=35 mm interpolation radius,
!rnorm=32 mm normalization radius.
!angle=180 maximum angle, anglz=0 starting point for interpolation.

- This text file defines a dipole geometry.

  The first section defines the problem constraints. Note that $reg is used before and $ after this input section.

Air Region

Poisson/Pandira
Problem

Finite Permeability
Using Table

0.1 is for mm.
1 is for cm.
2.54 is for inch

```
$reg mat=1, kprob=0, mode=0,conv=.1,
xmin=0,xmax=150.,
     kmax=50,
ymin=0, ymax=100.,
     lmax=50,
icylin=0,
xminf=0., xmaxf=25,ktop=11
yminf=0.0, ymaxf=10,ltop=5
ktype=121,nptc=31 nterm=14,rint=20, rnorm=25, angle=90, anglz=0
ienergy=1,
nbsup=0, nbslo=1, nbsrt=0, nbslf=0$
```

x and y limits
k and l limits

No cylindrical
symmetry
icylin=1 is cylindrical
symmetry problem

- The last part of the first section describes the edit constraints.

This section describes the limits of the output edit. The x limits are 0 to 25 mm, the y limits are 0 to 10 mm. 11 points are used for x ($\delta x = 2.5$ mm) and 5 points are used for y ($\delta x = 2.0$ mm).

```
$reg mat=1, kprob=0, mode=0,conv=.1,
xmin=0,xmax=150.,
    kmax=50,
ymin=0, ymax=100.,
    lmax=50,
icylin=0,
xminf=0., xmaxf=25,ktop=11
yminf=0.0, ymaxf=10,ltop=5
ktype=121,nptc=31 nterm=14,rint=20, rnorm=25, angle=90, anglz=0
ienergy=1,
nbsup=0, nbslo=1, nbsrt=0, nbslf=0$
```

This line describes the edit for the Fourier analysis of the beam. Ktype=121 means (1=dipole, 2=multipole interval, 1= midplane Neumann boundary, third digit 0= midplane Dirichlet boundary. nptc=31 means number of points on the circle, rint=20 means interpolation on 20 mm radius arc, rnorm=25 means multipole normalization at 25 mm, angle=90 and anglez=0 means the edit points are from 0 to 90 degrees. nterm=14 means the maximum number of multipole terms.

ienergy=1 means calculate the stored energy in joules/meter. ienergy=0 means don't calculate the stored energy.

- The last line in the first section describes the boundary conditions. nbs<u>up</u>, nbs<u>lo</u>, nbs<u>rt</u> and nbs<u>lf</u> means the boundary condition at the upper, lower, right hand, and left hand boundaries. = 0 means Dirichlet (flux parallel) and =1 means Neumann (flux perpendicular) boundaries.

```
$reg mat=1, kprob=0, mode=0,conv=.1,
xmin=0,xmax=150.,
     kmax=50,
ymin=0, ymax=100.,
     lmax=50,
icylin=0,
xminf=0., xmaxf=25,ktop=11
yminf=0.0, ymaxf=10,ltop=5
ktype=121,nptc=31 nterm=14,rint=20, rnorm=25, angle=90, anglz=0
ienergy=1,
nbsup=0, nbslo=1, nbsrt=0, nbslf=0$
```
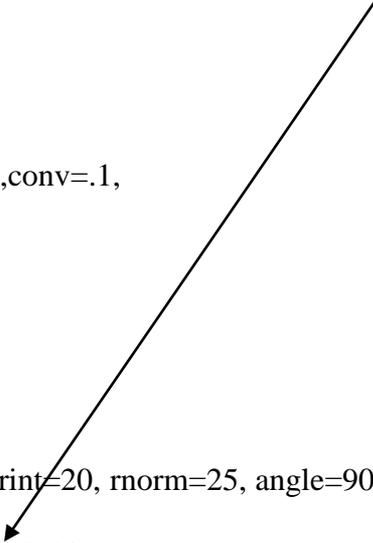
- Geometry Definition. Note that all regions must close, that is the first and last coordinates are equal. Each line must begin and end with $ or & sign.

Problem rectangular boundary. It uses the material definition given in the first section, mat=1 means air or vacuum.

Coil region is defined by its boundary, material specification mat=1 and the current value in Amps. Negative currents in the right hand coil gives positive flux on the horizontal centerline. *Coil regions can be single points and/or lines*.

The iron yoke area uses mat=2, which uses the BH curve for a "generic" iron whose magnetic properties approximate the behavior of 1010 steel.

```
!first region is air (mat=1), defines
the problem limits.
$po x=0, y=0$
$po x=150, y=0$
$po x=150, y=100$
$po x=0, y=100$
$po x=0, y=0$

!Coil
$reg mat=1 cur=-20000$
$po x=55, y=25 $
$po x=75, y=25 $
$po x=75, y=45 $
$po x=55, y=45 $
$po x=55, y=25$

!Iron Yoke
$reg mat=2$
$po x=0, y=25 $
$po x=40, y=25$
$po x=50, y=50$
$po x=80, y=50$
$po x=80, y=0 $
$po x=120, y=0 $
$po x=120, y=80$
$po x=0, y=80$
$po x=0, y=25$
```

Lattice Text Writing Techniques

- *I* find it easier to develop the geometry lattice using the *Excel*.

=CONCATENATE(C$1,A5,C$2,B5,C$3)

boundary		$po x=$, $y=$ $
xb	yb	
0	0	$po x=0, y=0$
150	0	$po x=150, y=0$
150	100	$po x=150, y=100$
0	100	$po x=0, y=100$
0	0	$po x=0, y=0$

Coil		
xc	yc	
55	25	$po x=55, y=25$
75	25	$po x=75, y=25$
75	45	$po x=75, y=45$
55	45	$po x=55, y=45$
55	25	$po x=55, y=25$

| Yoke		
xy	yy	
0	25	$po x=0, y=25$
40	25	$po x=40, y=25$
50	50	$po x=50, y=50$
80	50	$po x=80, y=50$
80	0	$po x=80, y=0$
120	0	$po x=120, y=0$
120	80	$po x=120, y=80$
0	80	$po x=0, y=80$
0	25	$po x=0, y=25$
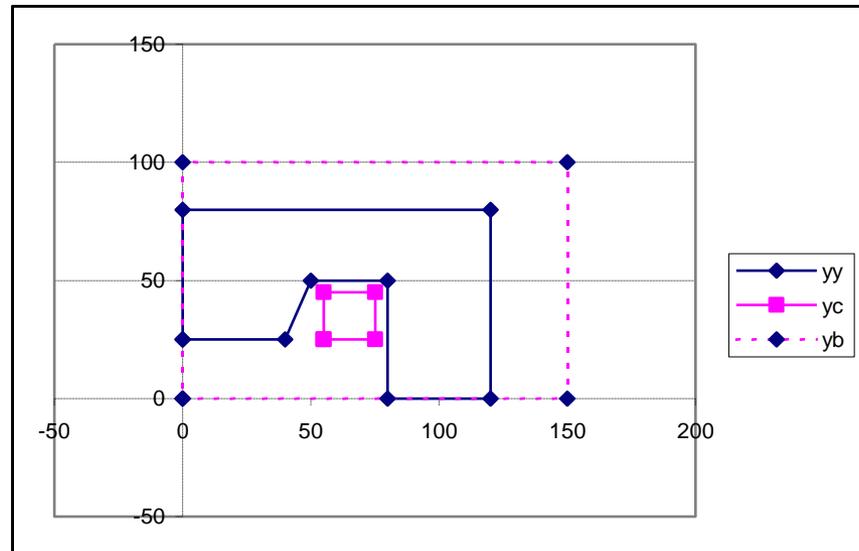
Copy and Paste

Symmetric Quadrupole

- $reg mat=1, kprob=0, mode=0,conv=.1
- xmin=0, xreg1=50.0, xreg2=235, xmax=301.65,
- kreg1=60, kreg2=200, kmax=220,
- ymin=0.0, yreg1=30.0, yreg2=108, ymax=301.65,
- lreg1=40, lreg2=120, lmax=220,
- icylin=0,
- xminf=0, xmaxf=230,
- yminf=0, ymaxf=0,
- ktype=4,
- nbsup=0, nbslo=1, nbsrt=0, nbslf=1,
- ktype=241,nptc=46 nterm=14,rint=30, rnorm=32.5, angle=45, anglz=0$
- !first region is air (mat=1)
- !problem type is poisson
- $po x=0.0, y=0.0$
- $po x=301.65, y=0.0$
- $po x=301.65, y=301.65$
- $po x=0.0, y=0.0$

- $reg mat=1 cur=10700$
- $po x=128.175, y=55.152$
- $po x=205.74, y=99.264$
- $po x=230.190, y=56.655$
- $po x=152.625, y=12.543$
- $po x=140.4, y=33.848$
- $po x=128.175, y=55.152$

Spear3 Quadrupole

S:\LANL3\Q.TXT 11-13-2000 12:54:24
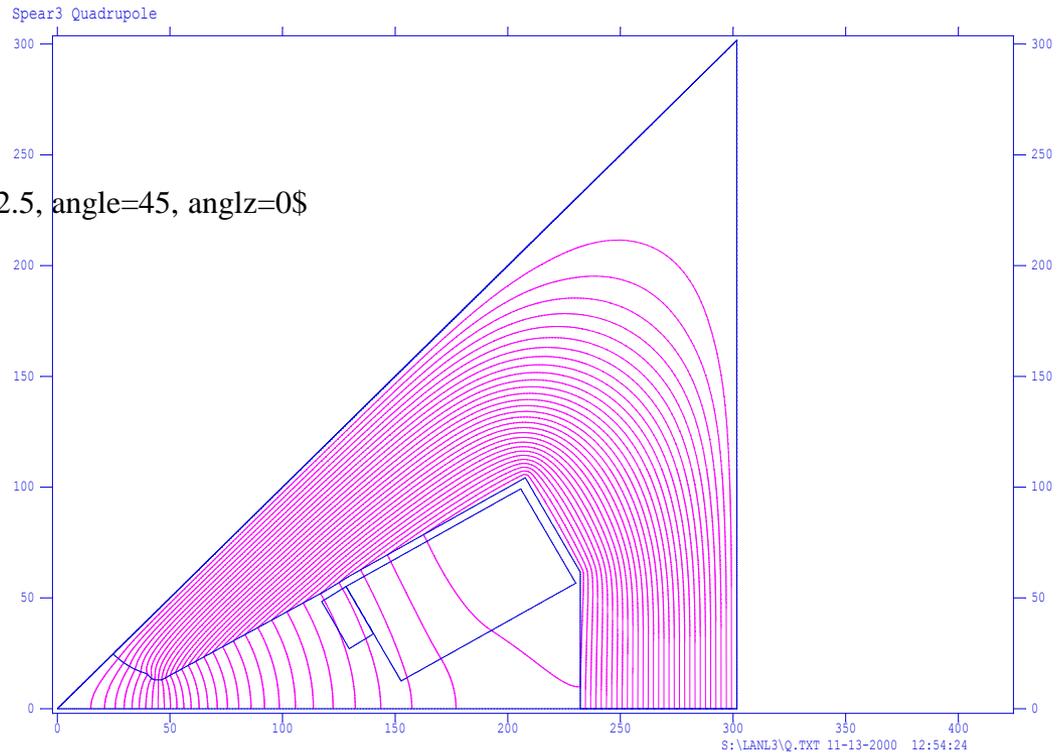
- $reg mat=1 cur=135$
- $po x=117.380, y=48.379$
- $po x=128.175, y=55.152$
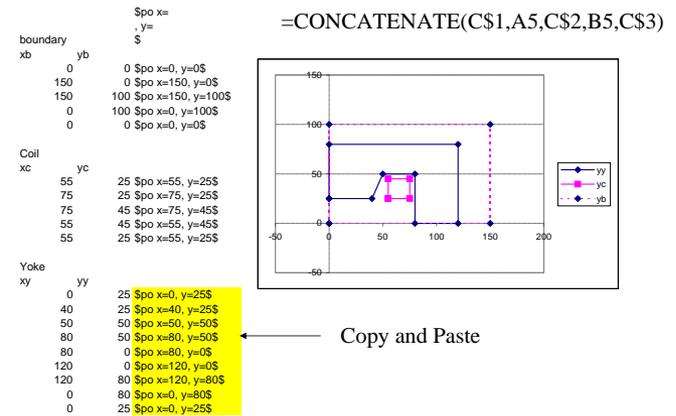- $po x=140.4, y=33.848$
- $po x=129.605, y=27.075$
- $po x=117.380, y=48.379$

- $reg mat=2$
- $po x=24.75, y=24.75$
- $po x=25.124,y=24.382$
- $po x=26.482,y=23.129$
- $po x=29.063,y=21.075$
- $po x=31.731,y=19.296$
- $po x=34.429,y=17.798$
- $po x=37.159,y=16.679$
- $po x=38.959,y=16.097$
- $po x=39.768,y=15.647$
- $po x=40.494,y=15.006$
- $po x=41.171,y=14.227$
- $po x=41.905,y=13.615$
- $po x=42.7,y=13.215$
- $po x=43.544,y=13.022$
- $po x=45.902,y=13.0$
- $po x=46.436,y=13.093$
- $po x=46.683, y=13.206$
- $po x=119.38, y=53.379$
- $po x=130.175, y=60.152$
- $po x=207.740, y=104.264$
- $po x=232.19, y=61.655$
- $po x=232.19, y=0.0$
- $po x=301.65, y=0.0$
- $po x=301.65, y=301.65$
- $po x=24.75, y=24.75$

A line boundary region defines the *Neumann* boundary condition along a diagnoal line.

- $reg ibound=0$
- $po x=0., y=0.0$
- $po x=24.75, y=24.75$
- $po x=301.65, y=301.65$

Using POISSON in Conformally Mapped Geometries

- In addition to analyzing the performance of a high performance geometry, POISSON can be used analyze the performance of mapped geometry. However, the mapping algorithm is highly nonlinear. Therefore, when a dipole geometry (which is well understood) is mapped into a quadrupole geometry, the entire quadrupole area is highly distorted and the boundaries of the extremities of the geometry can be very large compared to the area where the fields need to be resolved.

- Because of this limitation, means of modeling a smaller boundary in the quadrupole space needs to be understood.

Conformal Mapping

- The figure shows the simple dipole (the baseline case) described in the earlier section of this lecture.

- The output edit instruction requested a vector potential edit on a circular boundary which enclosed the required good region and a portion of the pole.

		$po x= , y= $	=CONCATENATE(C$1,A5,C$2,B5,C$3)	
boundary				
xb	yb			
0	0	$po x=0, y=0$		
150	0	$po x=150, y=0$		
150	100	$po x=150, y=100$		
0	100	$po x=0, y=100$		
0	0	$po x=0, y=0$		
Coil				
xc	yc			
55	25	$po x=55, y=25$		
75	25	$po x=75, y=25$		
75	45	$po x=75, y=45$		
55	45	$po x=55, y=45$		
55	25	$po x=55, y=25$		
Yoke				
xy	yy			
0	25	$po x=0, y=25$		
40	25	$po x=40, y=25$		
50	50	$po x=50, y=50$		
80	50	$po x=80, y=50$	Copy and Paste	
80	0	$po x=80, y=0$		
120	0	$po x=120, y=0$		
120	80	$po x=120, y=80$		
0	80	$po x=0, y=80$		
0	25	$po x=0, y=25$		

Mapping the dipole (w-space) into quadrupole (z-space) maps half the angle and generates a mesh where the corner of the dipole maps into a very large multiple of the magnet gap, *h*.

Review from Lecture #3
Mapping a Dipole into a Quadrupole

- In order to map the dipole into the quadrupole, we use the polar forms of the functions;

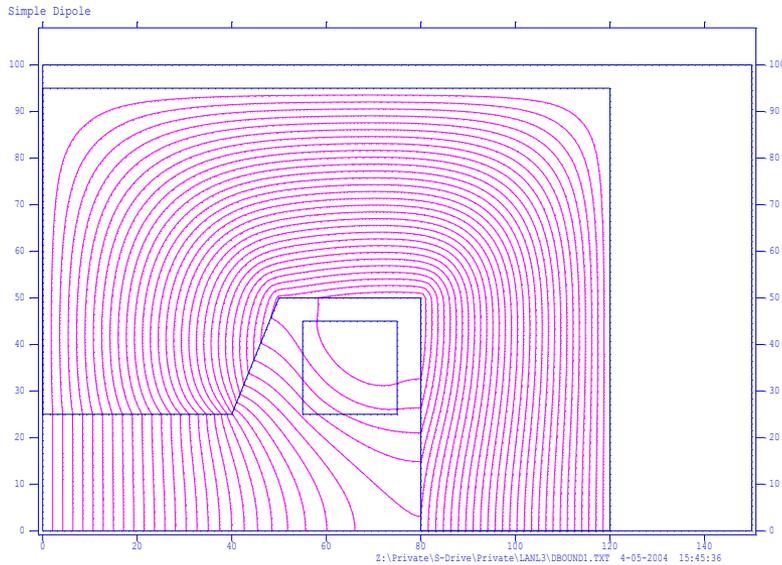$$w = |w|e^{i\varphi} \quad \text{and} \quad z = |z|e^{i\theta}$$

Since $w = \dfrac{z^2}{h}$ was used to convert the quadrupole into the dipole, $z^2 = hw = h|w|e^{i\varphi}$.

$$z = \sqrt{h|w|}\,e^{i\frac{\varphi}{2}} = |z|e^{i\theta} \quad \text{therefore;} \quad |z| = \sqrt{h|w|} \quad \text{and} \quad \theta = \frac{\phi}{2}$$

Finally;
$$x = |z|\cos\theta = \sqrt{h|w|}\cos\frac{\phi}{2}$$
$$y = |z|\sin\theta = \sqrt{h|w|}\sin\frac{\phi}{2}$$

The upper figure is the POISSON solution for the full quadrupole. The text file is from the POISSON edit where the values of the vector potential is evaluated on a fixed radius enclosing the pole tip and the required good field region. The lower figure is the POISSON calculation using a mesh in which the vector potential values are used for the boundary condition.

Harmonic analysis
Interpolated points on an arc of radius = 58.95
centered at (XORG,YORG) = (0.0,0.0)
K,L is nearest mesh point to physical coordinates X,Y.

n	Angle	X	Y	K	L	Avector
1	0	58.95	0	40	1	-5.01E+04
2	5	58.7257	5.1378	40	5	-5.03E+04
3	10	58.0544	10.2366	40	8	-5.09E+04
4	15	56.9413	15.2574	39	12	-5.18E+04
5	20	55.3949	20.1621	38	16	-5.30E+04
6	25	53.4268	24.9133	36	19	-5.43E+04
7	30	51.0522	29.475	35	22	-5.54E+04
8	35	48.289	33.8123	33	26	-5.65E+04
9	40	45.1583	37.8923	31	29	-5.77E+04
10	45	41.6839	41.6839	29	32	-5.26E+04
11	50	37.8923	45.1583	26	34	-4.69E+04
12	55	33.8123	48.289	23	37	-4.07E+04
13	60	29.475	51.0522	21	38	-3.44E+04
14	65	24.9133	53.4268	18	40	-2.82E+04
15	70	20.1621	55.3949	15	42	-2.21E+04
16	75	15.2574	56.9413	11	43	-1.63E+04
17	80	10.2366	58.0544	8	44	-1.07E+04
18	85	5.1378	58.7257	5	44	-5.31E+03
19	90	0	58.95	1	44	-3.83E-11

- A is the quadrupole POISSON flux plot from the dipole mesh using the vector potential boundary.
- B is an "optimized" dipole contour.
- C is the POISSON flux plot from the mapped "optimized pole contour.

Spear3 Quadrupole
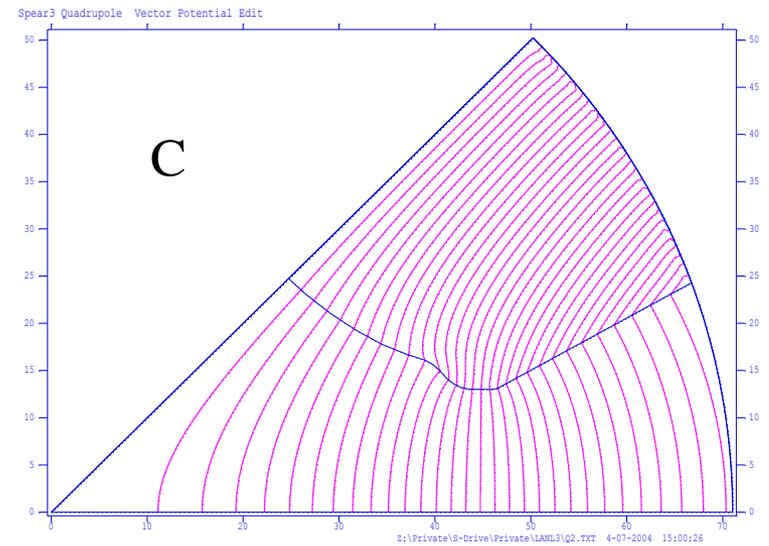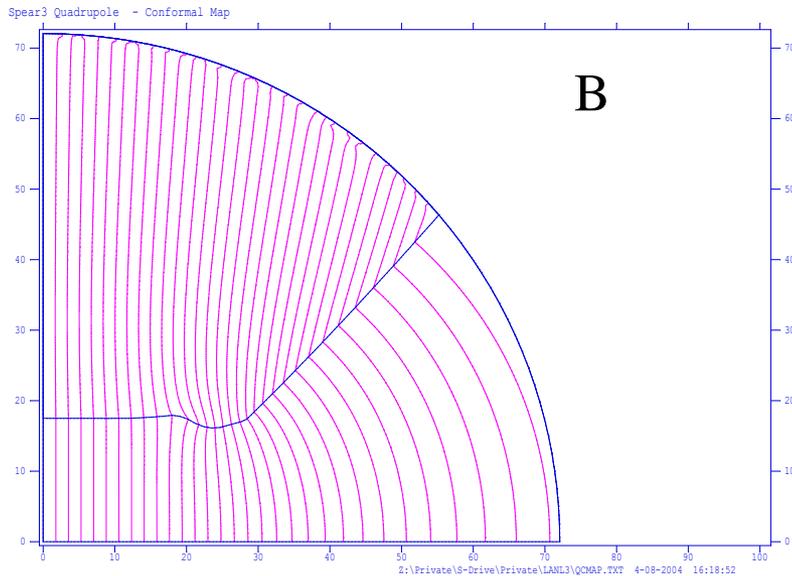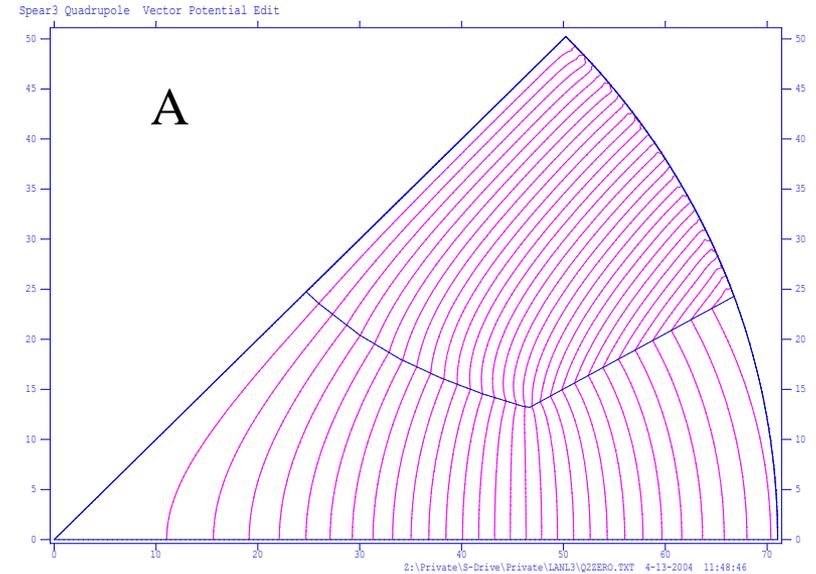
The final Poisson flux plot describes the field distribution using the actual quadrupole yoke and coil geometry.

S:\LANL3\Q.TXT 11-13-2000 12:54:24
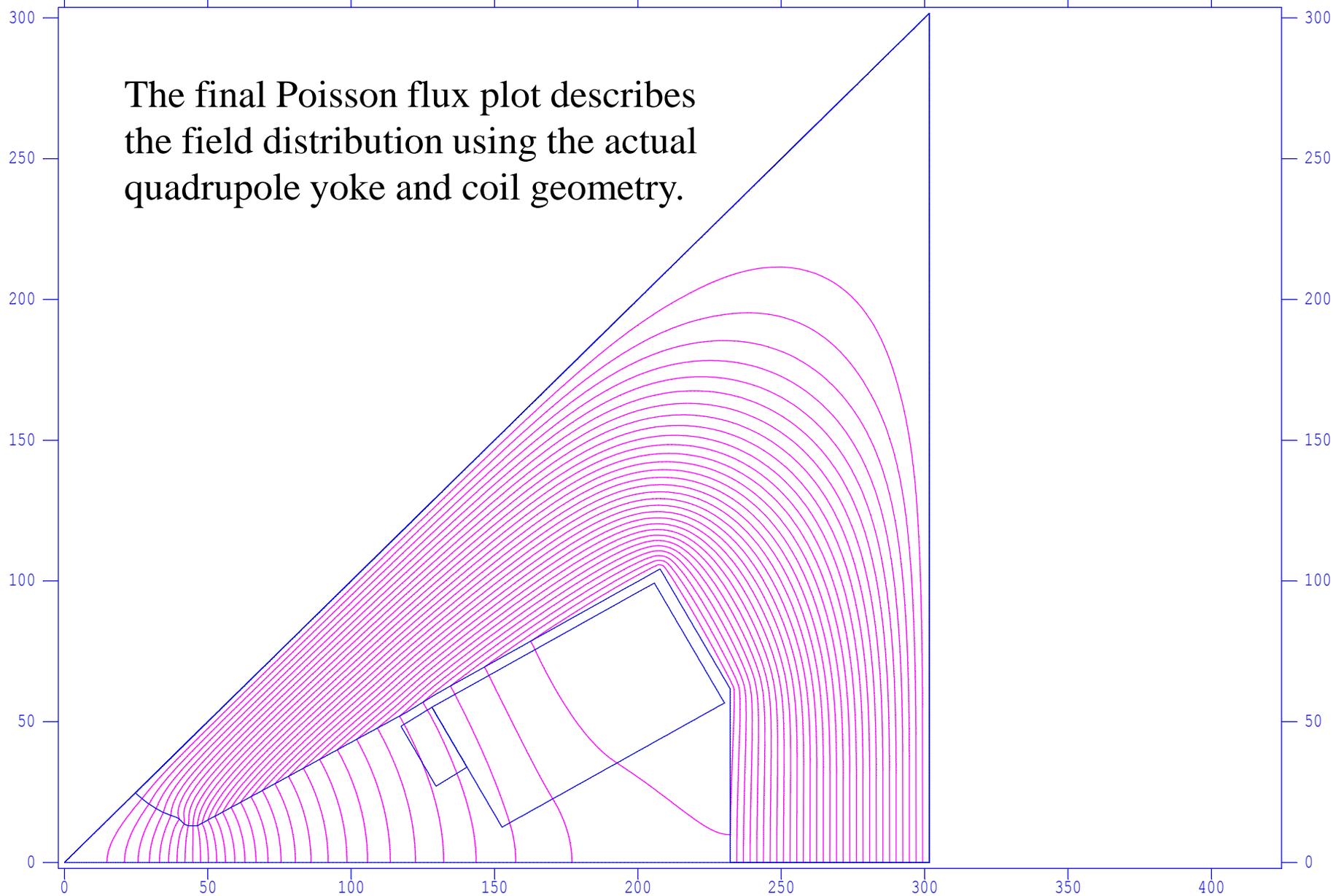
- Although there are many commercial software packages which perform two and three dimensional magnet calculations, POISSON uses the "language" of magnetics and allows one to compute the vector potential around a boundary and performs the harmonic analysis which are used to track the beam in existing lattice codes.

- Most of the accelerator community uses this tool, thus it is the software package of choice for me.

- The individual student should investigate other packages which may be more user friendly. In particular, the meshing package for POISSON is rather weak and often does not have the flexibility nor is robust enough to generate difficult detailed meshes easily.

Homework

- This lecture will be followed by a computer laboratory session.
  - If you haven't already done so, please read thoroughly and carefully chapter 6 of the text. Pay special attention to the section which presents the writing of the text file. An example writing the coordinates using a spreadsheet is illustrated by Fig. 4 on page 142 of the text.
- Familiarize yourself with Problem 6.1 on page 169 of the text.
- The examples of the conformally mapped geometry, although important, may take too much time to understand and to execute properly during this week. The student is encouraged to study the examples carefully and to run these, or similar cases, when he/she returns home.
- If you have the opportunity to do so, begin making the calculations of the parameters and the quadrupole poletip geometry and compute the current required to produce the required excitation in problem 6.1.
  - An expression needed to calculate this excitation is eq. 5.12 in chapter 5, the chapter covered in lecture 6.
  - We will work together writing the text file and running POISSON during the next session.

Lecture 5

- Chapter 4 of the text covers the material which will be presented in lecture 5, Perturbations.
- Although much effort can be invested to define pole geometry which will result in a uniform magnet, errors in fabrication, assembly or design assymetry can introduce error fields which can compromise the magnet performance.
- This chapter and lecture will cover the multipole field errors introduced in an otherwise perfectly designed magnet.
    - In many ways, these errors are much more important and damaging than those limited by the design.
    - This is because these errors are lower order multipoles which vary as a lower power of the radius and thus damp less quickly than the "allowed" multipoles.
- Understanding the next lecture will be enhanced if chapter 4 is read before the next lecture.