

# **SLD User's Guide**

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The Solenoid Lattice Designer (SLD) is a Windows program for designing solenoid lattices for ionization cooling channels. The program displays the coil configuration graphically and shows the location of the peak field and peak hoop stress in the coils. It shows the solenoid field on-axis as a function of  $z$ , shows the beta function as a function of  $z$ , and shows the beta function as a function of momentum. It can also display the force distribution inside the coils, a grid of the off-axis magnetic field, magnetic lines of force, or the Fourier components of the on-axis field. It also contains a built-in optimizer.

## 1. Starting the program

The program can be started from a DOS (command) window using the command

```
C:> sld
```

or

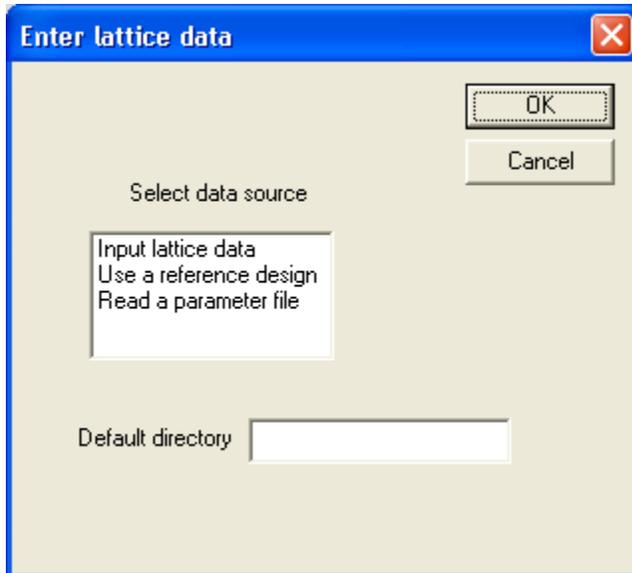
```
C:> sld file.prm
```

where *file.prm* is the name of an existing parameter file.

The program can also be started by clicking on its Windows icon.

## 2. Opening screens

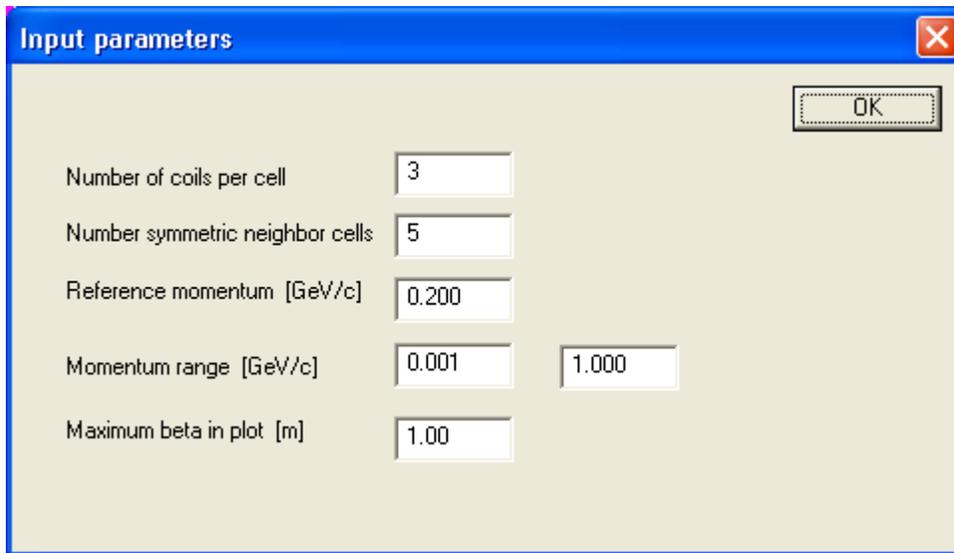
The figure shows the opening screen when the program is started without specifying a pre-existing parameter file.



The user has three choices to enter the lattice design data. The first choice allows inputting the data by filling out a set of dialog windows. The second choice brings up a list of built-in reference designs. The last choice is to read in an existing parameter file that has been previously saved or created offline. The directory for reading and writing files may also be changed here.

## 2.1 Entering data using the dialog windows

If the user chooses to input the data by hand it brings up the window

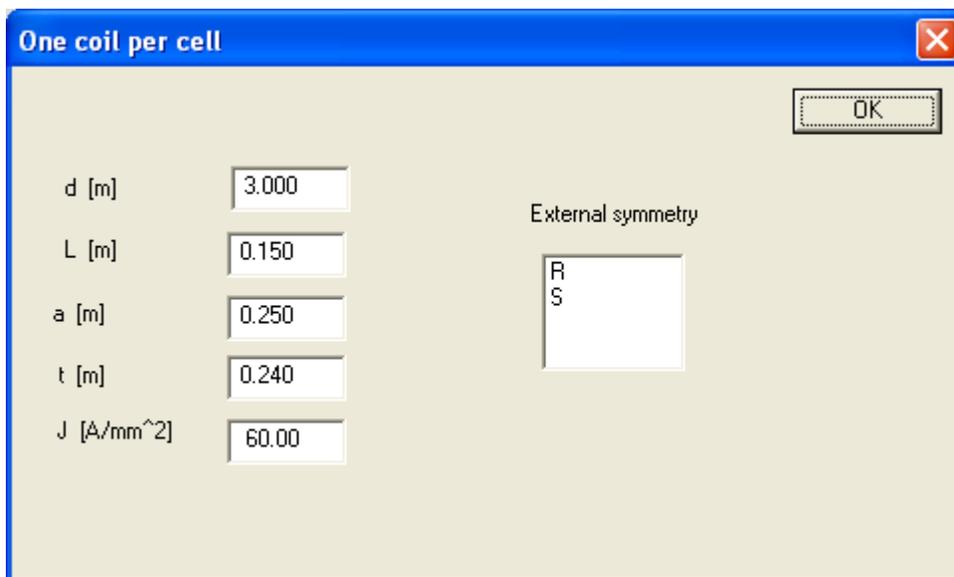


The 'Input parameters' dialog window contains the following fields and values:

Parameter	Value
Number of coils per cell	3
Number symmetric neighbor cells	5
Reference momentum [GeV/c]	0.200
Momentum range [GeV/c]	0.001 to 1.000
Maximum beta in plot [m]	1.00

The number of coils per cell must be from one to four. The next window that comes up depends on the number of coils per cell.

For 1 coil per cell the following window comes up.



The 'One coil per cell' dialog window contains the following fields and values:

Parameter	Value
d [m]	3.000
L [m]	0.150
a [m]	0.250
t [m]	0.240
J [A/mm <sup>2</sup> ]	60.00

External symmetry: R

**d** is the cell length, **L** is the coil length, **a** is the coil inner radius, **t** is the radial thickness, and **J** is the current density. The external symmetry parameter controls the polarity of the currents in alternate cells in the lattice. **R** symmetry means the polarities are the same in every cell. **S** symmetry means the polarities of corresponding coils flip in alternate cells.

For 2 coils per cell the following window comes up.

Two coils per cell

OK

d [m] 3.000

L [m] 0.150

a [m] 0.250

t [m] 0.240

J1 [A/mm<sup>2</sup>] 60.00

J2 [A/mm<sup>2</sup>] 30.00

g [m] 0.600

External symmetry

R  
S

**J1** and **J2** are the current densities in the two coils, and **g** is the gap between the coils at the cell boundary.

For 3 coils per cell the following window comes up.

Three coils per cell

OK

d [m] 3.000

L<sub>f</sub> [m] 0.150

a<sub>f</sub> [m] 0.250

t<sub>f</sub> [m] 0.240

J<sub>f</sub> [A/mm<sup>2</sup>] 60.00

g [m] 0.600

L<sub>c</sub> [m] 0.150

a<sub>c</sub> [m] 0.300

t<sub>c</sub> [m] 0.272

J<sub>c</sub> [A/mm<sup>2</sup>] 30.00

External symmetry

R  
S

The symmetric coils nearest the boundaries are called the *focus* coils. The other coil centered on the midplane is called the *coupling* coil.

For 4 coils per cell the following window comes up.

The screenshot shows a window titled "Four coils per cell" with a close button (X) in the top right corner. The window contains several input fields and two dropdown menus. The parameters are organized as follows:

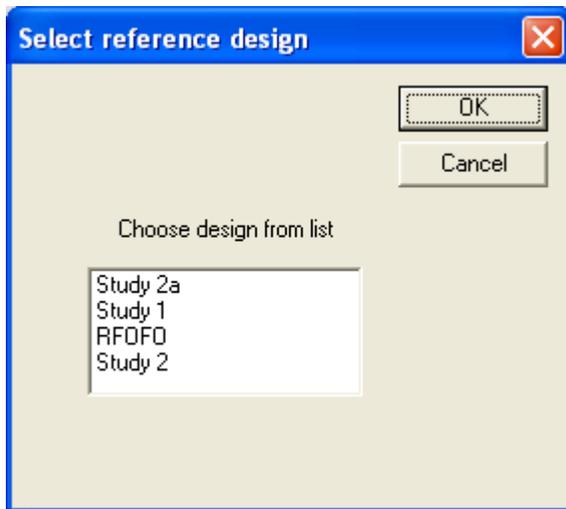
	a coil	b coil	
$z_0$ [m]	0.320	1.200	
L [m]	0.150	0.150	d [m] 3.000
a [m]	0.250	0.300	Internal symmetry
t [m]	0.240	0.272	External symmetry
J [A/mm <sup>2</sup> ]	60.00	30.00	

The "Internal symmetry" dropdown menu is set to "R". The "External symmetry" dropdown menu is set to "S". An "OK" button is located in the top right corner of the window.

The parameters of two of the coils ( $a$  and  $b$ ) must be specified.  $z_0$  is the distance of the left edge of the coil from the left cell boundary. The other two coils ( $c$  and  $d$ ) in the cell are determined by the *internal symmetry parameter*. **R** means the geometry and polarities are the same as the corresponding specified coils. **S** means the geometry is the same, but the polarities are flipped. **T** means the geometry is reversed, but the polarity is the same, i.e.  $c$  has the same geometry as  $b$ , etc. **ST** has both the geometry and the polarity reversed. The *external symmetry parameter* controls the polarity of the coils in alternate cells along the lattice. **R** means the polarities of all coils are the same as the corresponding coils in the original cell. **S** means the polarities of all coils are opposite from the corresponding coils in the original cell.

## 2.2 Entering a reference design

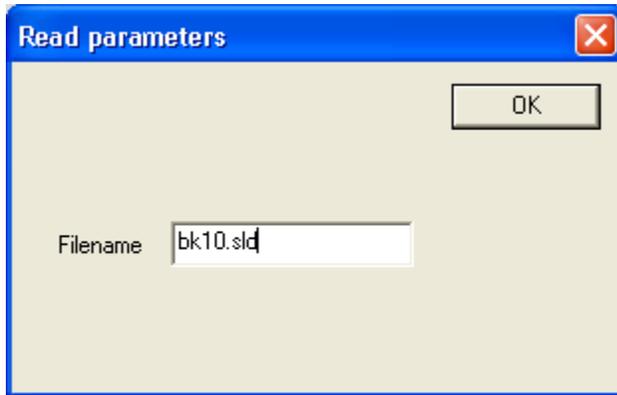
If the user chooses to enter a reference design it brings up the window



The user should click on an item in the list.

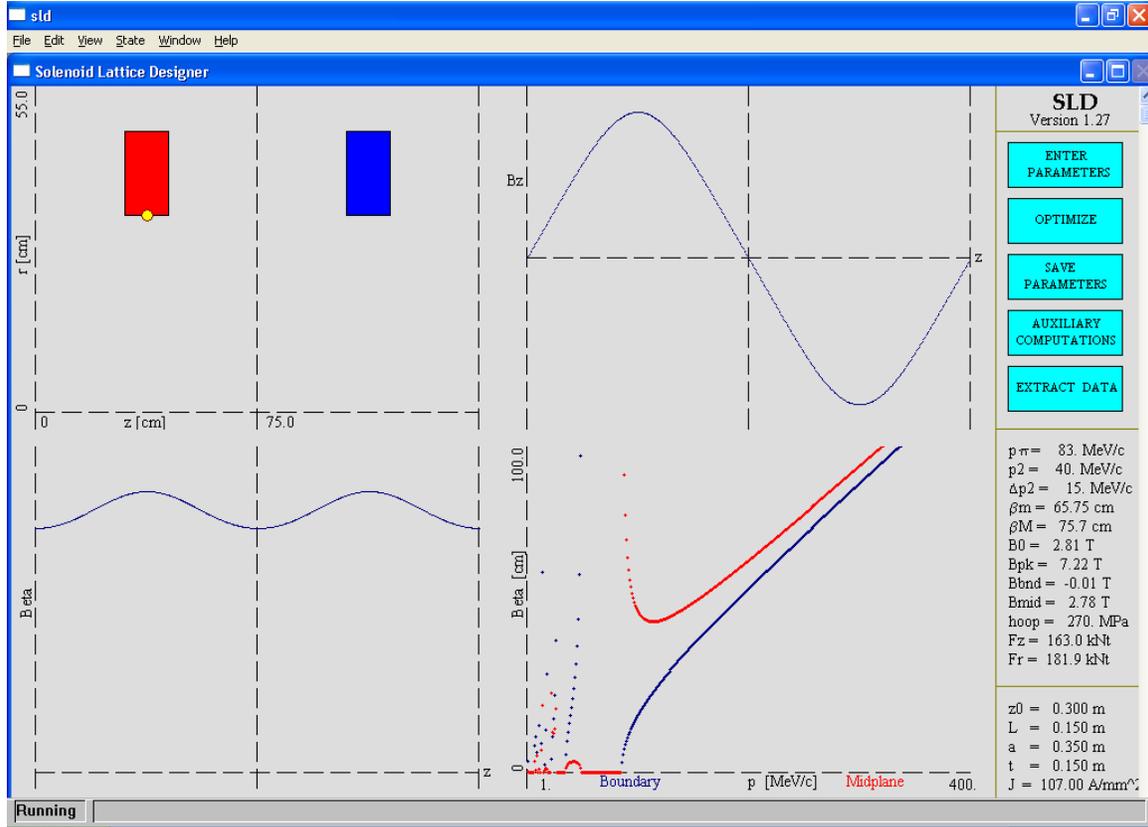
### 2.3 Entering a saved design

If the user chooses to enter a saved design, it brings up the following window.



### 3. Results screen

After a design has been entered the program displays a screen similar to the following.



The upper-left graph shows the coil geometry for two cells of the lattice. Coils with positive current are shown in red, while coils with negative current are shown in blue. The yellow circle on the coil shows the peak field location. The brown circle shows the location in the coils of the maximum hoop stress. The dashed vertical lines show the locations of cell boundaries.

The upper right graph shows the solenoidal field on-axis for two adjacent cells. The lower left graph shows the beta function as a function of  $z$ , evaluated at the reference momentum. The lower-right graph shows the beta function as a function of momentum. The beta function at the cell boundary is shown in blue, while the beta function at the cell midplane (midway between the boundaries) is shown in red.

The right hand panel is broken into four parts. The upper box indicates the version of the program that is running.

The second box contains five buttons that can be executed by clicking with the mouse. ENTER PARAMETERS brings up a series of windows for the user to enter the parameters for a new design. OPTIMIZE brings up a series of windows for the user to start an optimization study. SAVE PARAMETERS is used to save the parameters for a

design to a file. AUXILIARY COMPUTATIONS brings up additional calculations of the magnetic field grid, force distribution inside the coils, magnetic lines of force, or Fourier components of the on-axis field. EXTRACT DATA creates external ASCII files of selected information, such as the geometry, field or beta function data for a design.

The third box is used to display numerical values for some important coil properties and lattice characteristics:

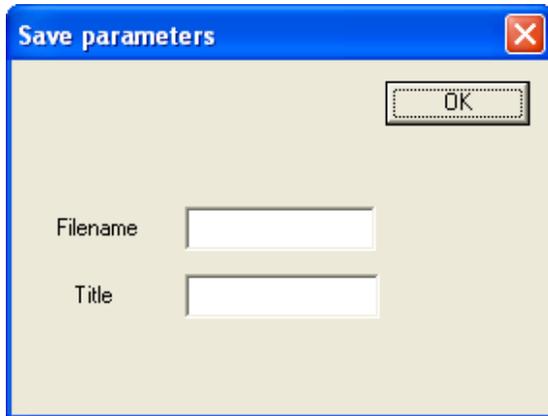
$p\pi$	upper momentum edge of $\pi$ resonance stop band
$p2$	central momentum of second pass band
$\Delta p2$	full width of second pass band
$\beta m$	minimum value of beta function at reference momentum
$\beta M$	maximum value of beta function at reference momentum
$B0$	maximum solenoid field on-axis
$Bpk$	peak field
$Bbnd$	solenoid field at cell boundary
$Bmid$	solenoid field at cell midplane
hoop	maximum hoop stress
$Fz$	maximum axial force
$Fr$	maximum radial force

The lower box contains data about the current parameters of a selected coil. The user determines what is displayed here by moving the mouse over the drawing of the desired coil in the left-most cell of the upper-left window. The information displayed is

$z0$	axial position of left edge of coil [m]
$L$	axial length of coil [m]
$a$	inner radius of coil [m]
$t$	radial thickness of coil [m]
$J$	engineering current density [ $A/mm^2$ ]

#### 4. Save parameters

This command is used to save the parameters for the current design.



Besides the name of the file the user can enter some descriptive information as the title.

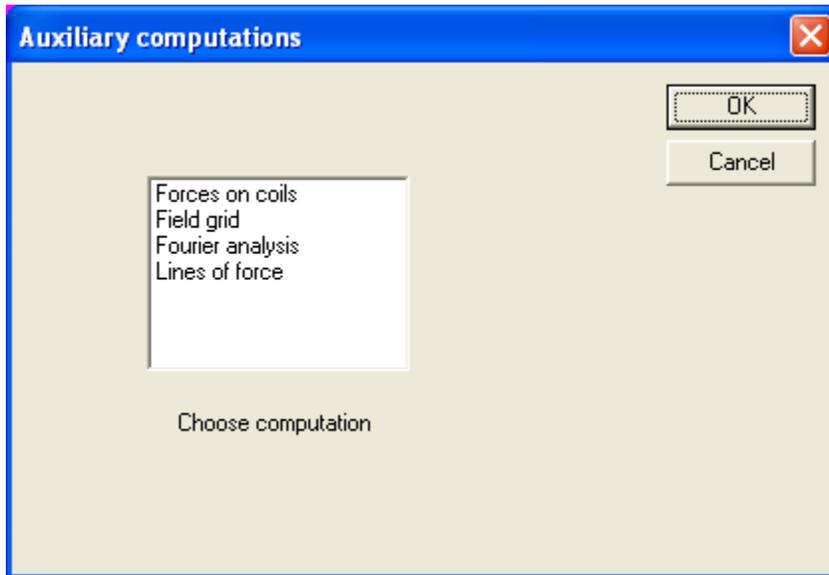
This file can also be created offline with a text editor. The format of the file is:

```
Title                (a80)
d g                 (R) d:cell period [m]  g: boundary gap [m]
pref pmin pmax     (R) reference, minimum, & maximum momentum [GeV/c]
btmx               (R) maximum value of beta in plot [m]
syms symi          (a3) external & internal symmetry parameters
                    syms = {R, S}
                    symi = {R, S, T, ST, N, X}
nsnc               (I) number of symmetric neighbor cells
ncpc               (I) number of coils per cell {1-50}
For i=1,ncpc
za(i) La(i) aa(i) ta(i) Ja(i) (R)
where za = axial position of left edge of coil [m]
      La = axial length of coil [m]
      aa = inner radius of coil [m]
      ta = radial thickness of coil [m]
      Ja = engineering current density [A/mm2]
```

If the user is creating an external file with more than 4 coils per cell or a non-symmetric lattice with 2-4 coils per cell, then set SYMI=N; otherwise set SYMI=X. For symmetric lattices with 4 coils per cell the user should enter SYMI the appropriate symmetric code from the set {R, S, T, ST}. Externally created files must have NCPC lines of coil data.

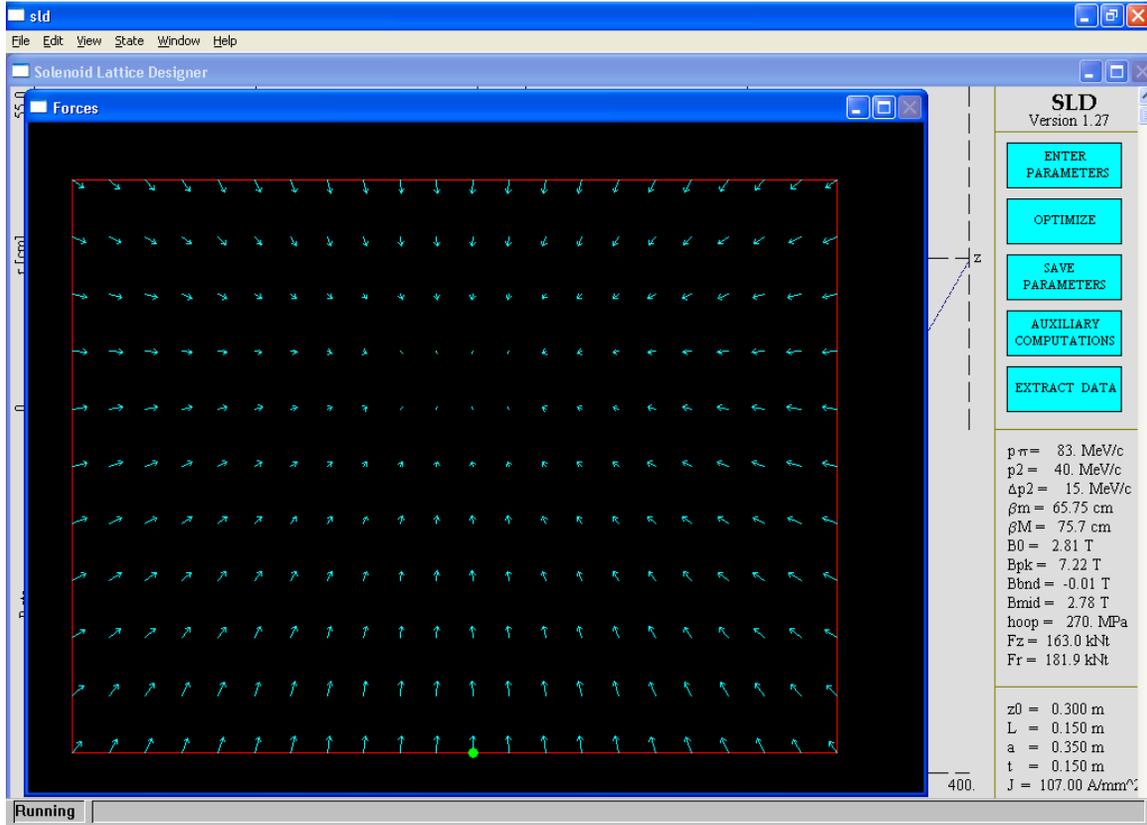
## 5. Auxiliary Computations

The AUXILIARY COMPUTATIONS button brings up a new window where the user may select additional calculations of the magnetic field grid, force distribution inside the coils, magnetic lines of force, or Fourier components of the on-axis field.



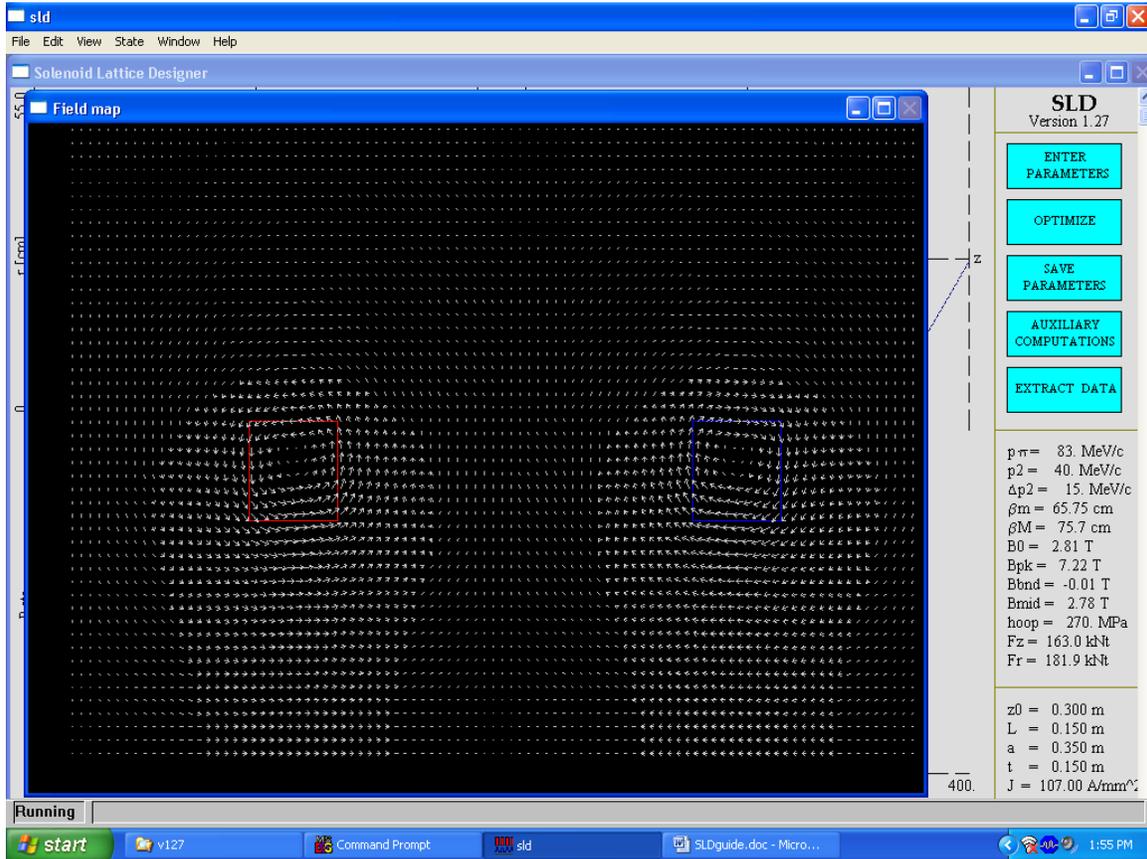
The user must select one of the items in the list and press OK.

Here is an example of forces on the coil.



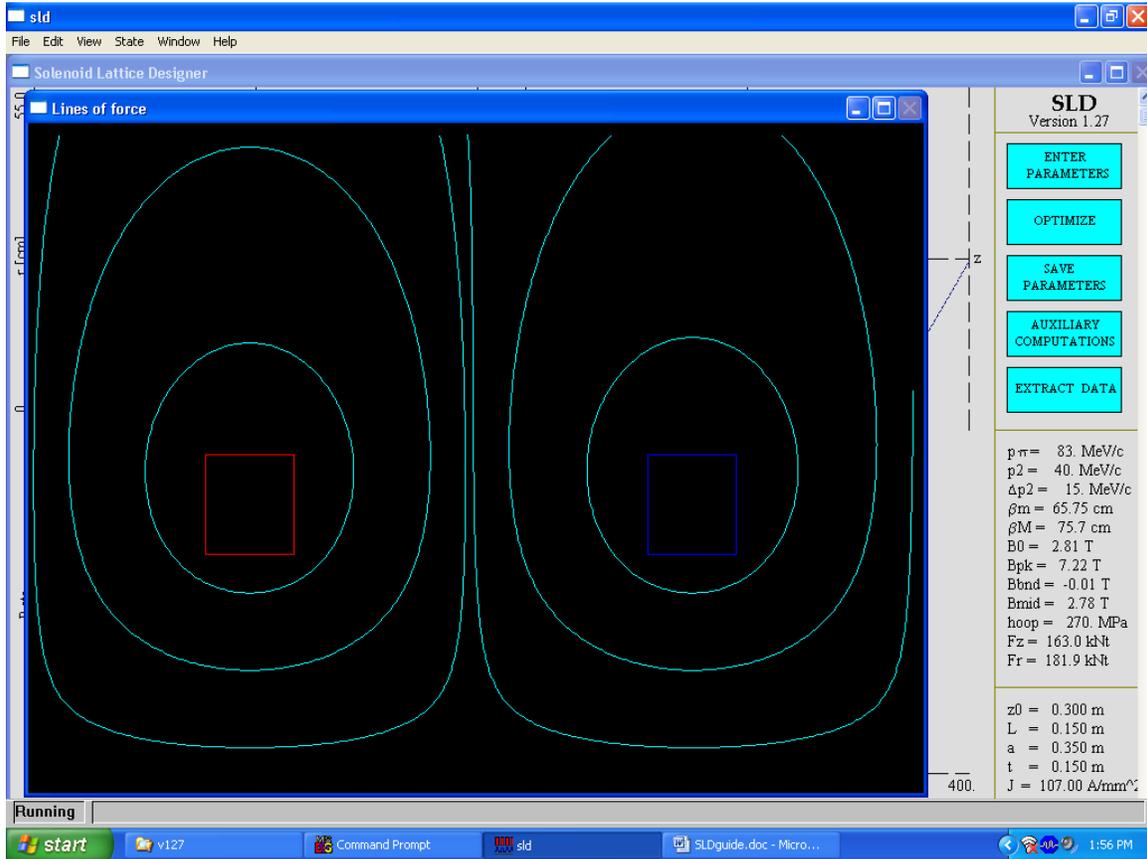
The location of the peak magnitude of the force is shown as a green circle. Symmetric coils in a lattice are not shown.

Here is an example of a magnetic field grid. There is a delay of 20-30 seconds while the grid is being calculated.

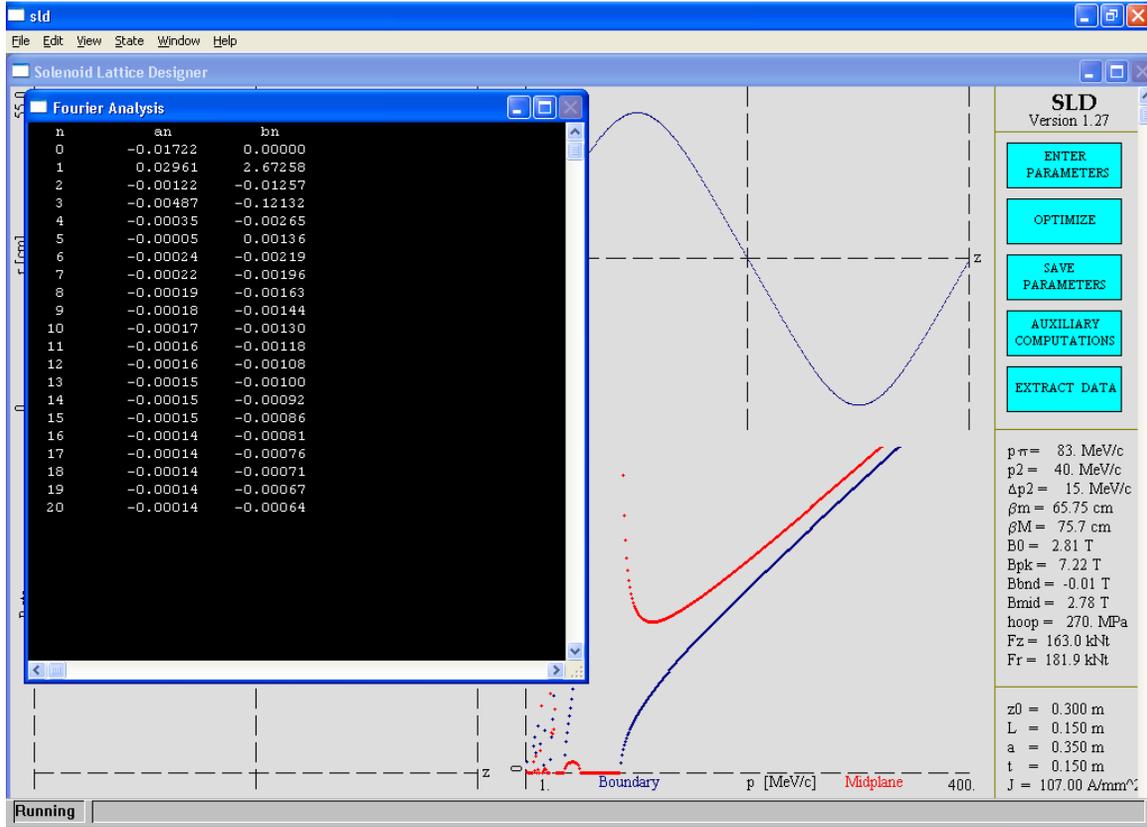


The coil positions are outlined in red and blue.

Here is an example of magnetic lines of force. There is a delay of 20-30 seconds while the grid is being calculated, unless the grid was calculated previously



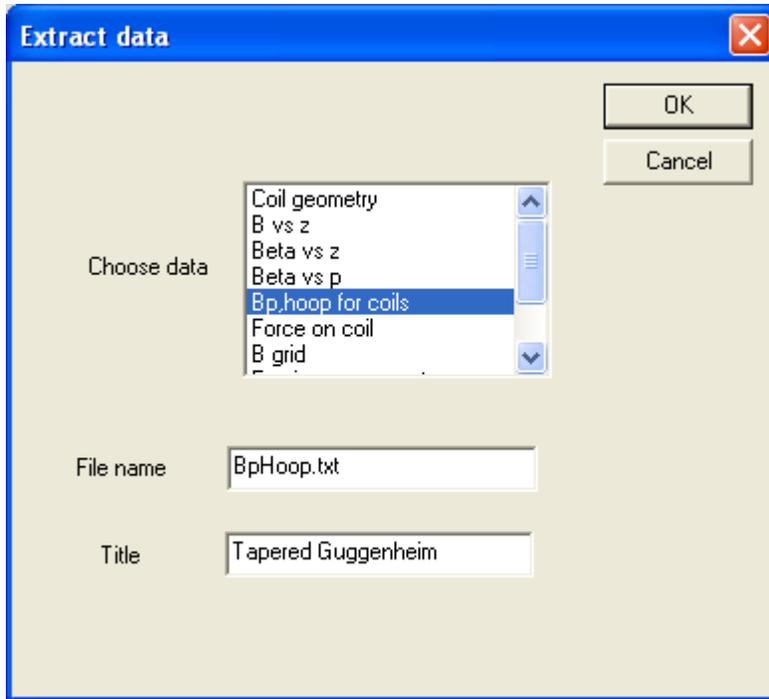
Here is an example of a Fourier analysis of the on-axis magnetic field.



The  $a_n$  coefficients are the cosine-like terms, while the  $b_n$  coefficients are the sine-like terms.

## 6. Extract Data

The EXTRACT DATA button can be used write selected information to an external file. This will bring up the following window.



The user can specify the file name where the data is written and can specify up to 80 characters of “title” information at the head of the file. The available choices are:

1. Coil geometry
2. B versus z  
This choice also lists  $dB/dz$  and  $d^2B/dz^2$ .
3. Beta function versus z
4. Beta function versus p  
This choice also lists the phase advance.
5. Peak field and hoop stress on coils
6. Forces on coils
7. B grid
8. Fourier analysis of on-axis field
9. Lines of force
10. All data

All available information is written to a single file.

## 7. Optimization

The first window controls some general properties of the optimizer.

Optimizer settings

OK

ppi [GeV/c] 0.100 p2 [GeV/c] 0.200

dp2 [GeV/c] 0.050

betab [m] 0.200 betam [m] 0.200

Bbnd [T] 0.000 Bmid [T] 0.000

External symmetry Internal symmetry Max iterations

R S R S T ST 100

Optimizer method

simplex  
direction set

LOG file? File name

Weights

Bpk 0.00

ppi 0.00

p2 0.00

dp2 0.00

betab 0.00

betam 0.00

Bbnd 0.00

Bmid 0.00

The progress of the optimization can be saved in an ascii log file. ppi is the desired value of  $p_\pi$ , p2 is the desired value of  $p_2$ , dp2 is the desired width of the second momentum pass band, betab is the desired value of  $\beta$  at the boundary, betam is the desired value of  $\beta$  at the midplane, Bbnd is the desired value of the field at the cell boundary, and Bmid is the desired value of the field at the cell midplane. The maximum number of iterations roughly controls how long the optimizer will continue. The weights determine the merit function for the optimization. At least one weight must be non-zero. There are weights for minimizing the peak field and getting the desired value for  $p_\pi$ ,  $p_2$ ,  $\Delta p_2$ ,  $\beta_b$ ,  $\beta_m$ , Bbnd, or Bmid.

The second optimizer window is used to enter specific information about the coils. For example, for one coil per cell

Active?	Guess	Lower limit	Upper limit
<input checked="" type="checkbox"/> L	0.150	0.100	0.200
<input type="checkbox"/> a	0.350	0.00	0.00
<input type="checkbox"/> t	0.150	0.00	0.00
<input checked="" type="checkbox"/> J	107.00	100.00	120.00
<input type="checkbox"/> d	0.75	0.00	0.00

OK

One must enter an initial guess for the values of all the parameters. The variables in the fit are selected by clicking on the desired Active buttons. Lower and upper limits must be entered for each of the active variables.

For two coils per cell the second optimizer window looks like

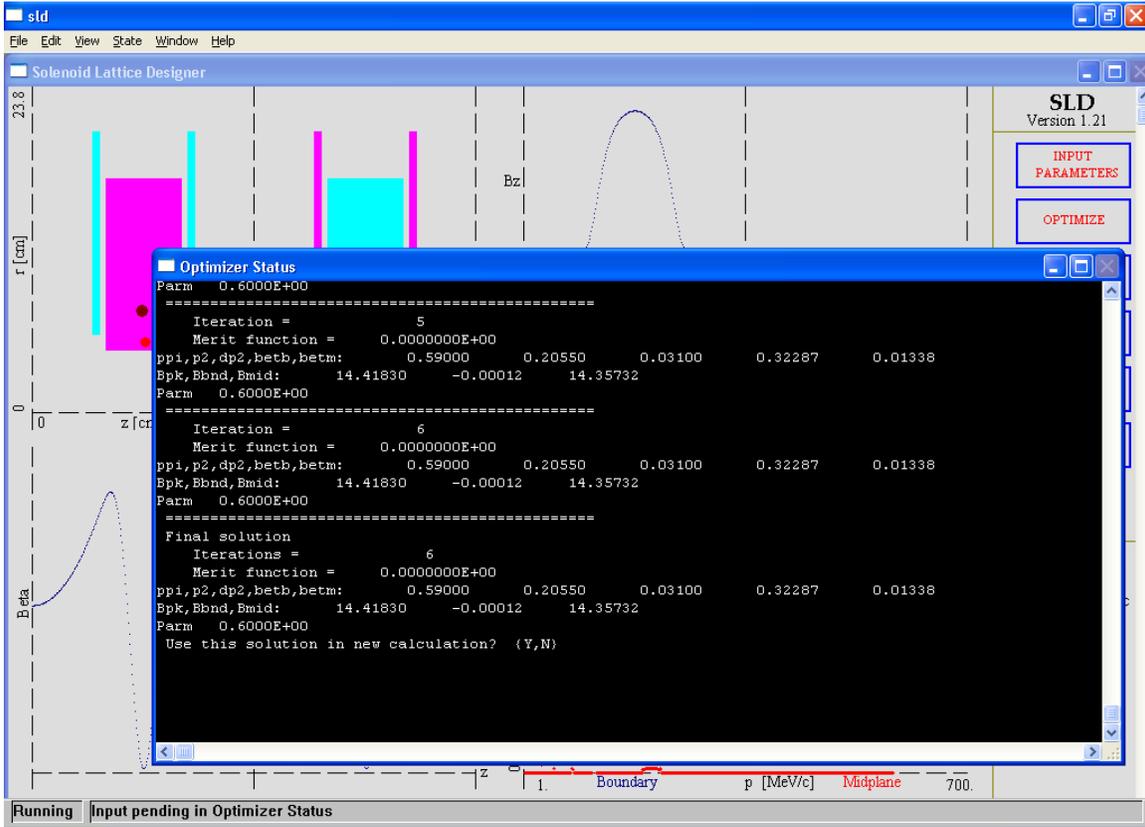
Active?	Guess	Lower limit	Upper limit
<input type="checkbox"/> L	0.500	0.35	0.65
<input type="checkbox"/> a	0.770	0.54	1.00
<input type="checkbox"/> t	0.110	0.08	0.14
<input checked="" type="checkbox"/> J1	95.30	66.71	123.89
<input type="checkbox"/> J2	-95.30	-123.89	-66.71
<input type="checkbox"/> g	0.600	0.42	0.78
<input type="checkbox"/> d	2.750	1.92	3.57

Force J2 = J1 ?  
 Force J2 = -J1 ?

OK

The window contains extra check boxes on the right to force the constraints that the current density in the second coil is  $\pm$  the current density in the first coil.

Once the optimization begins the progress is displayed in another window.



At completion one must type Y to replace the current solution with the optimizer results, or N to ignore it. Occasionally the optimizer will pass through the minimum before stopping. This can be checked by examining a log file.