Mirror Magnet Designs for the Recycler Ring

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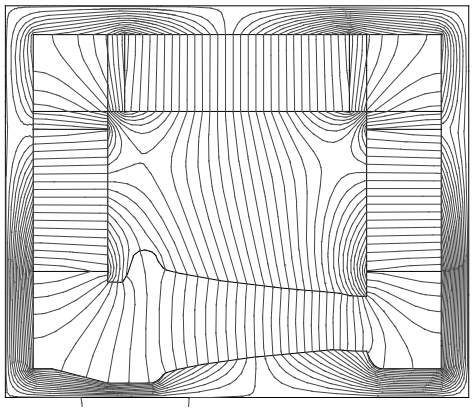
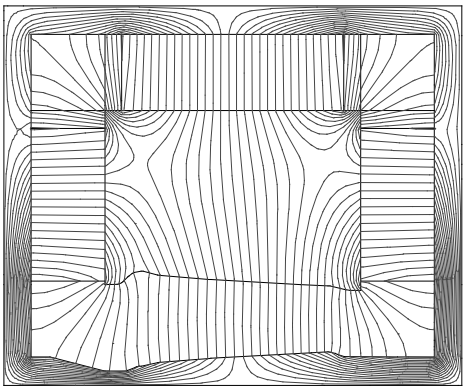
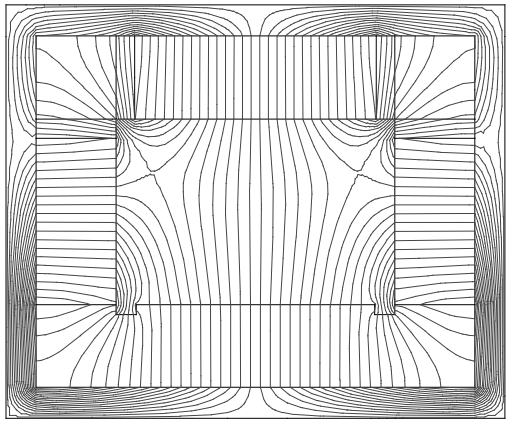


MGS



MGD



MDA

Introduction

This note describes the 2-D magnetic design of the Recycler Ring permanent magnet "Mirror Dipoles". The "Mirror Magnets" are used for Recycler beam transfers in situations where mechanical interference would occur between transfer line magnets and those for the circulating beam. By putting all of the magnetic material and a pole tip on one side of a relatively thin "mirror plate", it is possible to achieve the nominal strength and focussing characteristics of a gradient dipole while having the beam center less than 2" from the mechanical edge of the package. See fig. 1. This configuration greatly simplifies the design of the transfer lines by allowing the bend and focussing optics to mimic almost exactly the optics of the circulating beams in both the Main Injector and Recycler. The small beam separation required by a pair of mirror magnets also minimizes the kicker & Lambertson strengths required to transfer the beams.

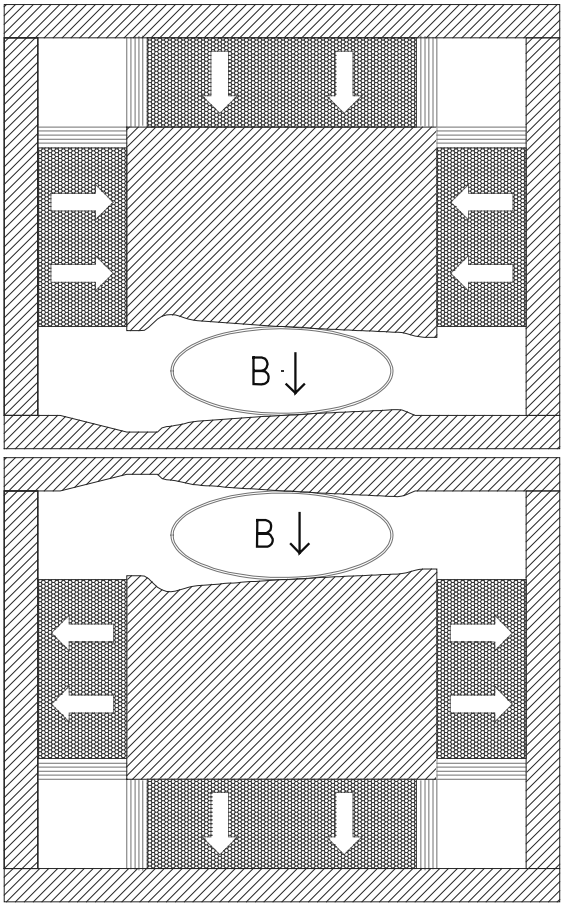


Fig. 1 - A pair of MGD Mirror magnets configured so the beam in each pipe sees the same bend & focussing field, while allowing a center-to-center beam spacing as small as 3.5". The polarization of the permanent magnet ferrite is opposite for the two magnets.

The magnetic specs for these are based on the gradient magnets of the RR_V18 lattice. Although all numbers in this document are believed to be correct, the controlling reference on the RR_V18 magnetic specifications is MI-170. The mechanical drawings of the individual magnets are in the Technical Division archives. The magnetic measurements (multipole defects, etc.) are being stored in the MTF database and hardcopies are included in the travelers.

Mirror Magnet Types - Three different types of mirror magnets were required for the Recycler beam transfers. They differ by gradient, septum width, required field quality, and magnetic strength and length. Single-page "spec sheets" for each of these are shown in figs 2-4. Calculated field quality plots are shown in figs. 5-7. The POISSON files for each are attached at the end of the document.

The **MGD** mirror magnets (fig. 2) are magnetic clones of the RGD gradient magnets. This is the only mirror magnet design that sees circulating beams of the Recycler, and therefore needs 10^{-4} field quality across a +/-1.4" horizontal aperture. Both polarities of MGD magnets are required (see fig. 1). Only two of the MGD magnets are in the circulating beam of the Recycler, both of the "septum down" configuration (this corresponds to the top magnet in fig.1). The septum width of the MGD is 0.75".

The **MGS** magnet (fig. 3) is a magnetic clone of the SGF gradient magnet. Only one is needed, and it is needed only because people were reluctant to chew a big hole in one of the FMI quads to get the beams out to the Recycler in a FMI dispersion suppressor region. It has a larger normalized gradient than the MGD and therefore required a larger slope on the mirror plate and a thicker (1") septum than the MGD. It also required rather extreme shaping on the wide-gap side of the upper pole tip to terminate the fields properly. The required field quality is ~0.1% since it is only used as a transfer line magnet. The required width of the good-field region is ~2.5" since it is immediately downstream of a Lambertson with a 2" square beam pipe.

The **MDA** magnet (fig. 4) is a zero-gradient (straight dipole) version of the MGD. Only one is needed, to merge the abort lines for the Recycler and FMI just upstream of the dump. A flat mirror plate and a pole tip with a single step at the edges easily meets the required field quality of ~0.5% across a 2" x 3" aperture.

MGD

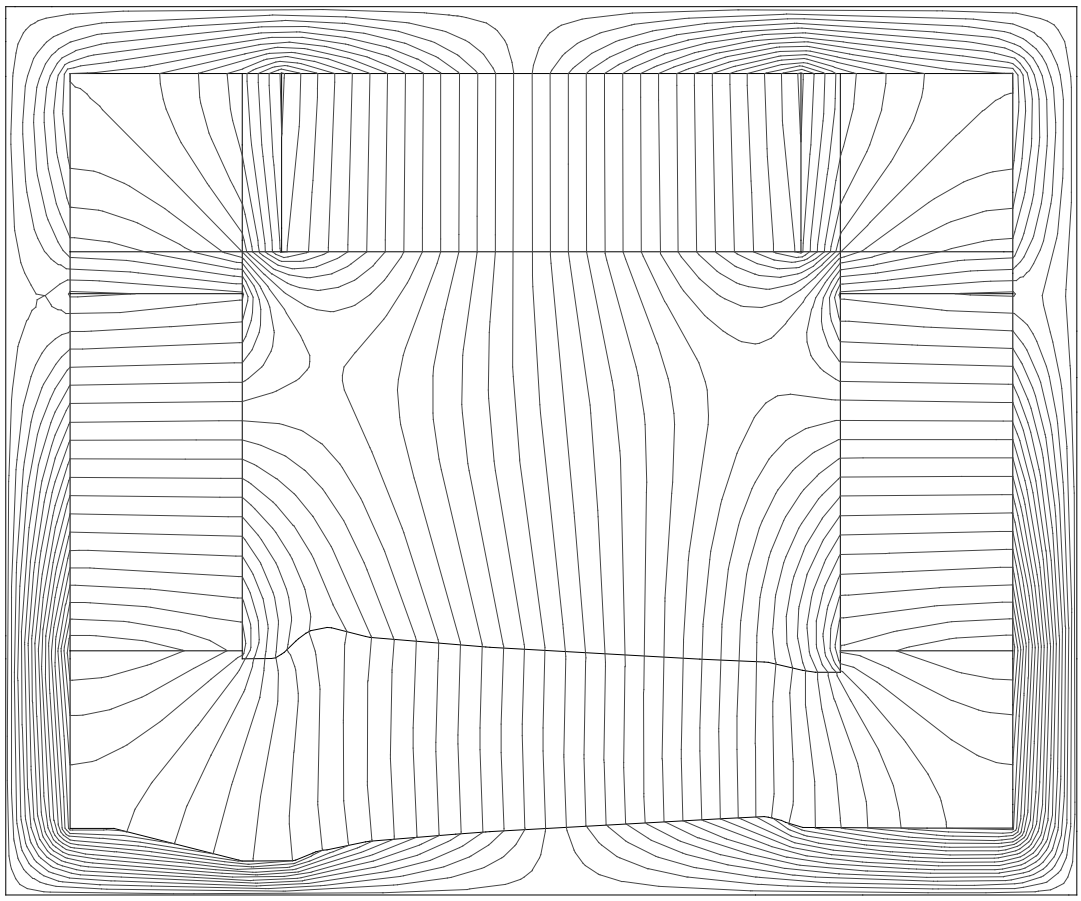


Fig. 2 - Recycler v18 MGD D-Gradient Mirror Magnet

```
Quantity:                  6 installed / 8 manufactured
Width:                12.500 in.  = 31.8 cm
Height:               10.000 in.  = 25.4 cm
Magnetic Length:       177.0 in.  = 4.496 m
Physical Length:     184.0 in.    = 4.673 m
Septum Width @center: 0.75 in.    = 1.9  cm
Magnet Gap @center:   2.00 in.    = 5.08 cm
Field quality (dBy/By)  .01%
Good Field Width:     3.00 in.    = 7.62 cm
Bend Angle:        21. mrad.
Beam Sagitta:      12. mm.
Dipole Field B0=       1.375 kG
Gradient     B1=       3.238 kG/m =  598.1 units @ 1"
Sextupole    B2=       -6.42 kG/m^2 =-15.1 units @ 1"
```

MGS

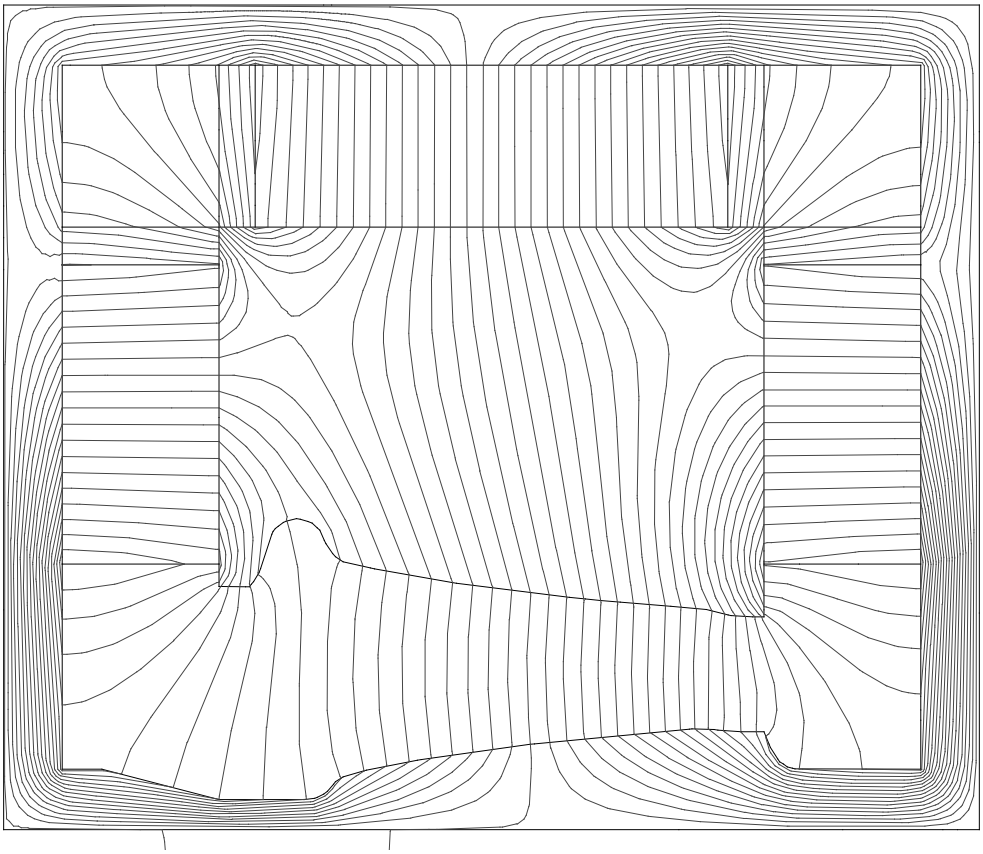


Fig. 3 - MGS Dispersion Suppressor F-gradient Mirror Magnet

```
Quantity:           1 installed / 2 manufactured
Width:                12.500 in.  = 31.8 cm
Height:               10.250 in.  = 26.04cm
Magnetic Length:       122.0 in.  = 3.099 m
Physical Length:       129.0 in.  = 3.277 m
Septum Width @center: 1.00 in.    = 2.54  cm
Magnet Gap @center:   2.00 in.    = 5.08 cm
Field quality (dBy/By)  .1%
Good Field Width:     3.00 in.    = 7.62 cm
Bend Angle:              14. mrad.
Beam Sagitta:             5. mm.
Dipole Field B0=       1.330 kG
Gradient     B1=       6.682 kG/m = 1276.0 units @ 1"
Sextupole    B2=        0.00 kG/m^2 =  0.0 units @ 1"
```

MDA

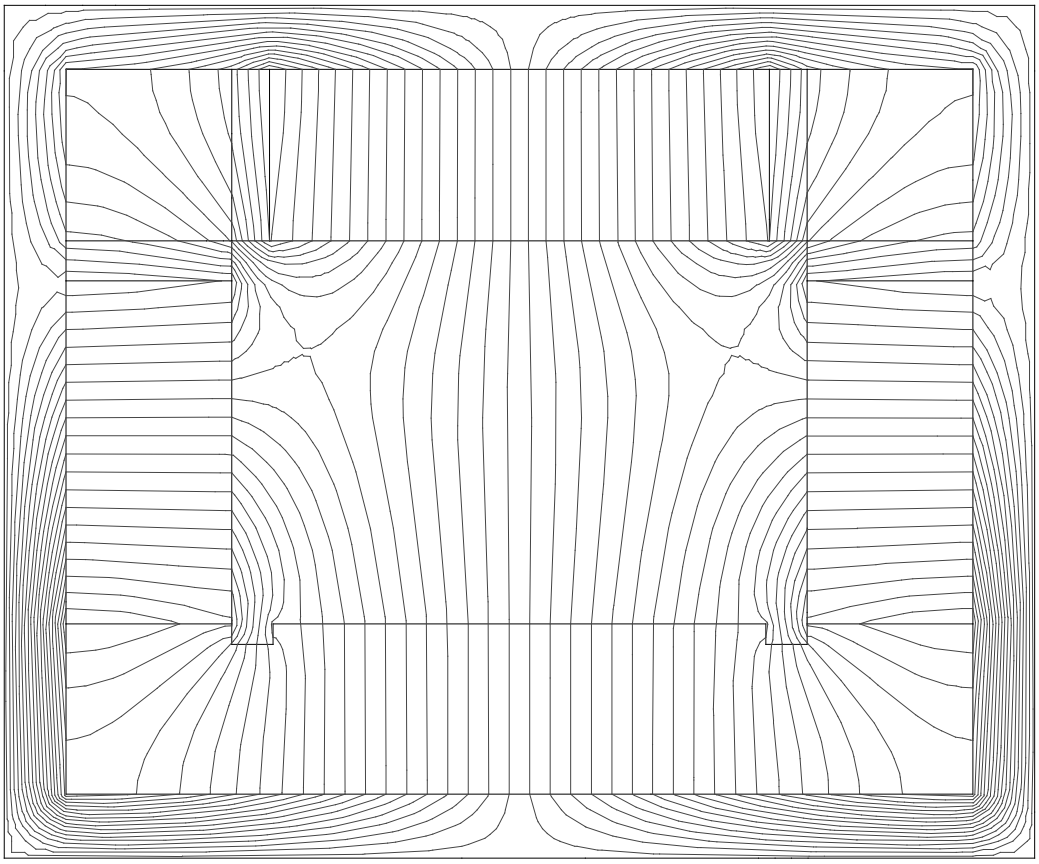


Fig. 4 - Recycler v18 MDA Abort Line Mirror Dipole

```
Quantity:           1 installed / 1 manufactured
Width:                12.500 in.  = 31.8 cm
Height:               10.000 in.  = 25.4 cm
Magnetic Length:       177.0 in.  = 4.496 m
Physical Length:     184.0 in.    = 4.673 m
Septum Width @center: 0.75 in.    = 1.9  cm
Magnet Gap @center:   2.00 in.    = 5.08 cm
Field quality (dBy/By)  .5%
Good Field Width:     3.00 in.    = 7.62 cm
Bend Angle:         21. mrad.
Beam Sagitta:       12. mm.
Dipole Field B0=       1.375 kG
```

Magnetic Materials - Strontium Ferrite (Br~0.38T, Hc~0.35T) was used. The properties of this material are discussed in the 8 GeV line section of the Main Injector design report, the Recycler design report, and various MI notes. Interspersed in the ferrite were strips of Nickel-Steel "compensator alloy" in an approximately 1:5 ratio of compensator : ferrite. The compensator has a temperature dependence of magnetization which cancels that of the ferrite [Dallas PAC papers by Bertsche, Foster..]. The amount of compensator was adjusted to null out the temperature coefficient of the magnets. The compensator in the mirror magnets differs from the Recycler magnets in that most of the compensator is provided by longitudinal strips which run the length of the magnets, as opposed to the 6" long strips interspersed with the ferrite of the Recycler gradient magnets. This arrangement permits the degree of temperature compensation to be conveniently adjusted after the magnet has been assembled. Details of the final compensator pattern for each magnet are in the travelers.

For the purposes of magnetic modeling, the compensator was accounted for by an ad-hoc reduction in the magnetic strength of the bricks, accomplished via a POISSON "stacking factor" of 0.7 for the ferrite. Since all magnetic materials are located behind the pole tips in the mirror magnets, the field shape is largely insensitive to the details of the magnetic driving material. In fact, essentially the same field shape can be obtained by replacing the ferrite material by two current sheets along the edges of the ferrite bricks. This allows one to model the magnets with codes that do not have explicit provisions for permanent magnet materials. All of my simulations used PANDIRA, a code provided as part of the POISSON package which does allow for permanent magnets.

The magnetic constants (".CON") file is reproduced below.

POISSON ".CON" FILE SPECIFYING MAGNETIC PROPERTIES
OF FERRITE AND COMPENSATOR ALLOY
(see POISSON documentation for explanation)

```
0  (0=Dump # to be read in from lattice)
*18 4 *6 0  *42 1 41  1 1  *54 0.0 4.0 0.0 1.0 s

6     1.00000     -1   mat stack type  (top block)
90.0 1.0 s
   -3500.00        3800.00        hcept bcept

7 1.0 -1   mat stack type   (right block,if used)
0.0 1.0 s
   -3500.00        3800.00        hcept bcept

8 1.0 -1   mat stack type   (Left block, if used)
180.0 1.0 s
   -3500.00        3800.00        hcept bcept

3 1.0 1   mat stack type (Compensator Carpenter
Type 30)
0         0.25
575       0.25
850       0.293103
1200      0.350877
1420      0.38587
2000      0.454545  count
end
```

Pole Tip Steel - The pole tips and mirror plate for the MGD mirror magnets were built using low-carbon 1008 steel, and the magnetic modeling used the B-H curves for 1010 steel provided with POISSON. The MGS and MGA mirror dipoles used 1018 steel since they were transfer-line-only magnets. The choice of 1008 steel (vs. the more commonly available higher-carbon 1018 or A36 grades) was made for conservatism rather than as the result of R&D.

Flux Return boxes were built from 1018 steel 3/4" thick. This keeps the maximum flux density below 1T in the flux return shells. In the mirror plate, there is a thin region where the flux was allowed to rise to ~1.3T.

Pole Tip Shape Optimization was performed using modified versions of the Recycler pole tip optimizer codes which are described in the MI note on the magnetic design of the Recycler RRv18 arc magnets. In the program, additional degrees of freedom were introduced to allow the top and bottom plates to have dissimilar shapes. This was necessary primarily to kill the large skew quad that arises in the simple mirror configuration. This skew quad arises because the field lines are not vertical at the edges of the magnet gap (see fig. 2) and this field defect (a skew quad) tends to propagate all the way to the center of the aperture. To counteract this effect it is necessary to turn down the edges of the pole tips, so the gap ends up shaped like a frown. This "terminates" the field

lines to a more vertical configuration near the edges of the gap and eliminates the skew quad. This behavior can be seen clearly on the MDA mirror dipole (fig. 4) in which it was only necessary to turn down the edges of the top pole tip in order to meet the field quality requirements.

It may be asked why a simple (flat) mirror plate would not suffice for the septum plate of the gradient magnets. A flat mirror plate is sufficient for the straight dipole (zero gradient) MDA magnet. A flat mirror plate will not work for the gradient magnets for the following reason: A flat plate with a gradient pole tip above it would have the correct (dipole + normal quad) field immediately above the surface of the mirror plate. However the beam lives 1 inch above the mirror plate, and the gradient field "feeds down" to a skew dipole when the field is re-expanded about the beam center. A glance at fig. 3 should convince you that the sloping bottom plate is necessary to ensure a vertical dipole field on the beam-center-midplane of the magnet.

The program also enforced several special constraints on the pole tip design. Among these were the minimum thickness of the mirror plate and the constraint that the final shape should be able to be cut with a 3/4" or 1" diameter ball mill. In practice the fitter proved very finicky due to the large number of degrees of freedom, and a hand-optimized starting point with ~1% field quality had to be obtained before the fit converged properly.

It was necessary to increase the pole tip width to 7" (vs. 6" for the Recycler arc magnets) to achieve the required width of the good-field region. Representative scans of the calculated field defect in By vs. X for the MGD magnets are attached. The field error is at the level of 1E-4 or below out to +/-1.5".

Acknowledgement author would like to thank Dick Gustafson for bringing this mirror configuration to his attention. Dick went so far as to build a small model magnet of this "Mirror" configuration in the early days of Recycler magnet R&D.

Table 1:
POISSON CALCULATED MULTIPOLES FOR RECYCLER V_18 MIRROR MAGNETS

	MGD			MGS			MDA		
	Target	Normal	Skew	Target	Normal	Skew	Target	Normal	Skew
Dipole	10000.00	10000	-0.11	10000.00	10000	0.14	10000.00	10000	-0.12
Quad.	-598.09	598.13	0.12	1275.96	1275.69	0.19		0.21	-1.20
Sextup.	-15.05	-15.04	0.02		0.60	-1.52		3.54	0.14
Octupole		-0.03	0.03		-0.24	0.25		-0.05	-1.85
10-pole		0.01	-0.13		-0.09	1.43		1.24	0.01
12-pole		-0.03	0.05		-0.08	-0.17		-0.01	-0.08
14-pole		0.04	0.04		0.31	-0.98		0.47	-0.01
16-pole		0.01	0.01		-0.46	0.35		0.01	0.03
18-pole		-0.02	-0.01		0.25	-0.10		0.09	0.00
20-pole		-0.05	-0.03		-0.01	0.02		0.01	0.00
22-pole		0.02	-0.02		0.04	-0.01		0.01	0.01

1. Multipoles are in Fermilab “units”, i.e. parts in 10,000 at radius of 1”.
2. All Multipoles are evaluated at a "Probe Radius" (Rint in Poisson) of 0.85".
3. All Multipoles are reported at a "Reference Radius" (Rnorm in Poisson) of 1.00".
4. Fit values of all skew multipoles are less than 0.05 units.
5. The grid size in POISSON must be DX=0.050” or smaller to get these results.

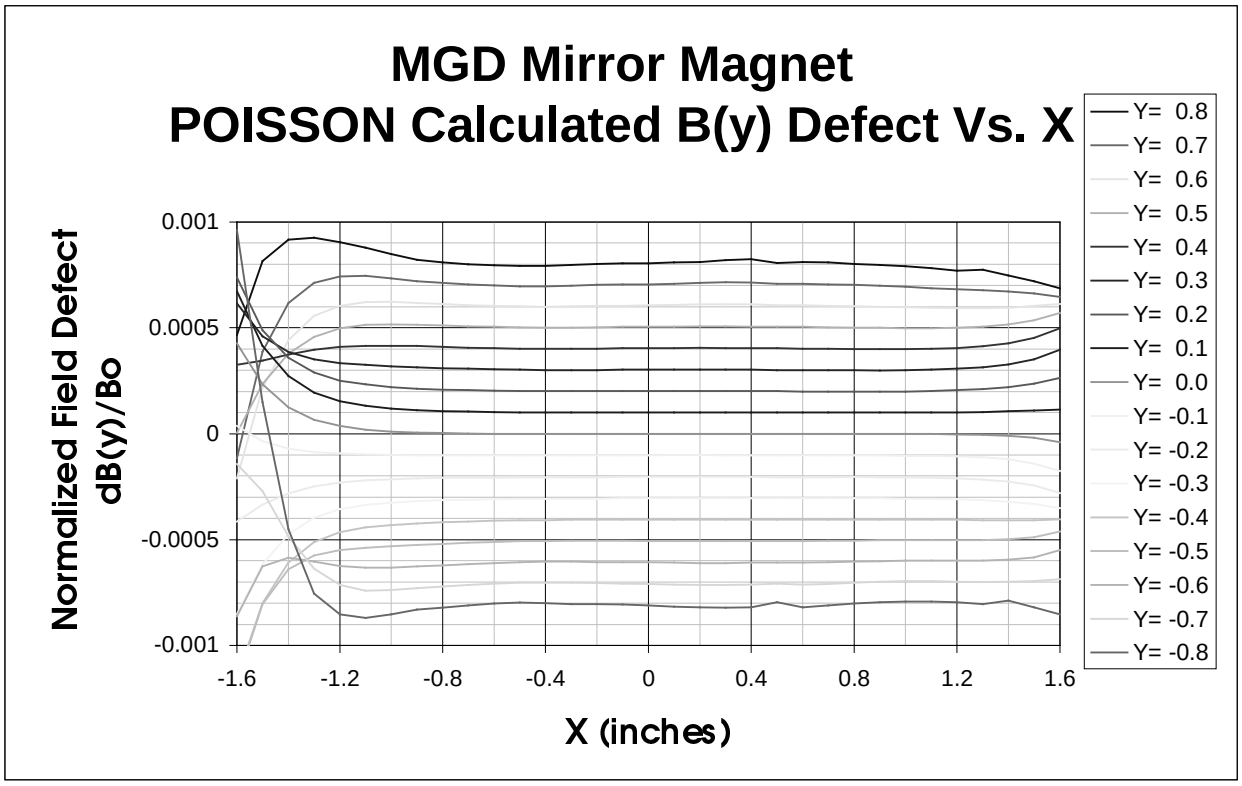


Fig. 5 - POISSON-calculated Field Defect (dB(y)/Bo) vs. X for MGD mirror dipole. The plot has scans at different at different values of Y, offset from each other by steps of 0.01%.

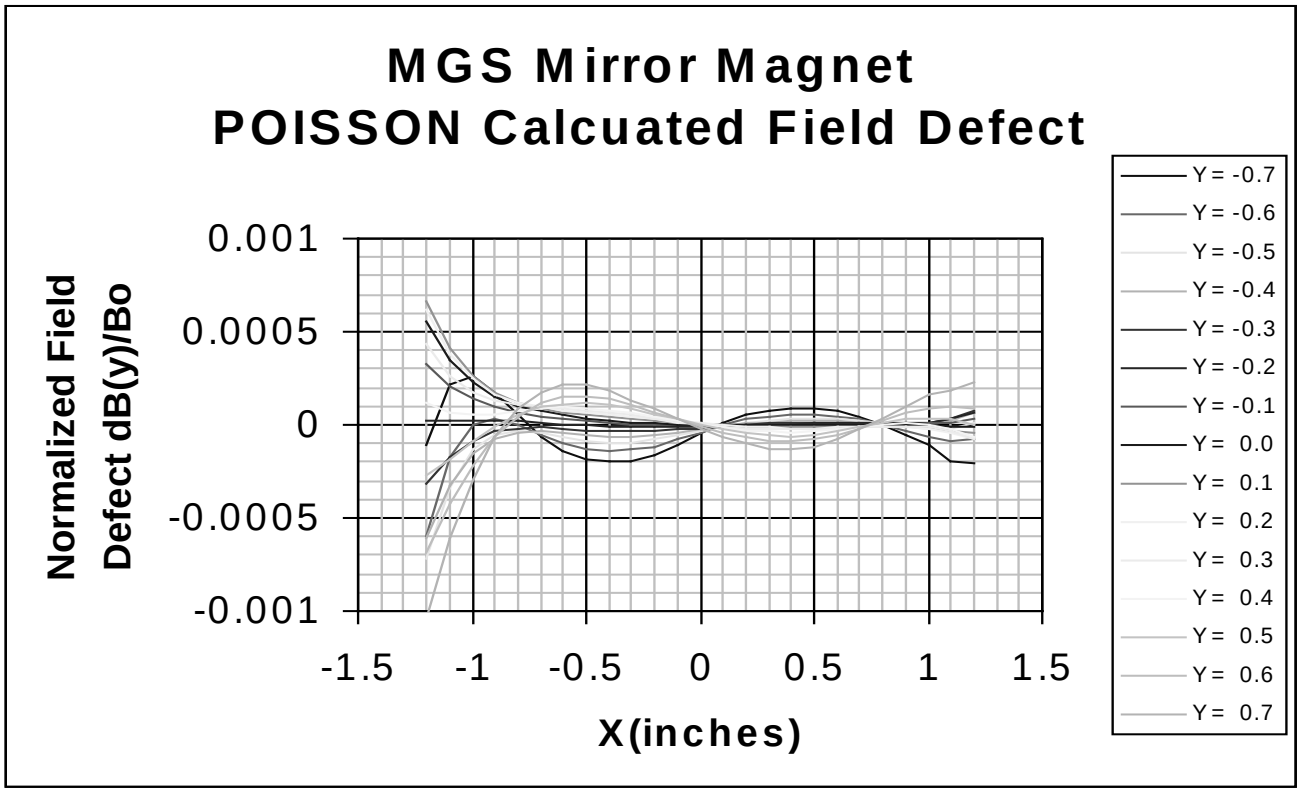


Fig. 6 - POISSON-calculated Field Defect (dB(y)/Bo) vs. X for MGS mirror dipole. The plot has scans at different at different values of Y, with NO individual offsets.

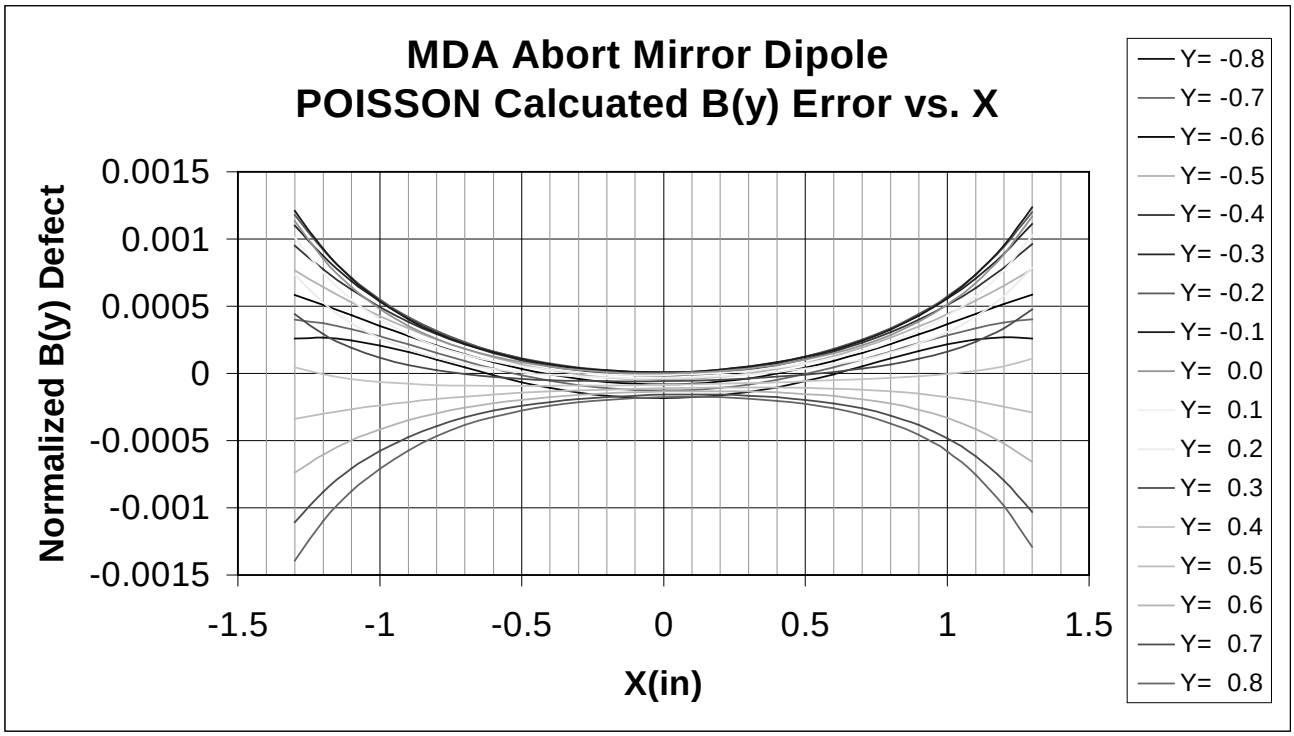


Fig. 7 - POISSON-calculated Field Defect (dB(y)/Bo) vs. X for MDA Abort mirror dipole.

Appendix 1 -MGD Mirror Magnet POISSON (PANDIRA) FILE

```
Recycler v18 MGD Mirror Magnet
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*** cutting with 1" Ball End Mill
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Xmin =   -6.75000    ,
Xreg1=   -4.10000    ,
Kreg1=          27,
Xreg2=    4.10000    ,
Kreg2=         191,
Xmax =    6.75000    ,
Kmax=          218,
Ymin=   -2.25000    ,
Yreg1=   -1.55000
Lreg1=           8,
Yreg2=   0.000000    ,
Lreg2=          44,
Yreg3=    1.60000    ,
Lreg3=          81,
Ymax=    8.75000    ,
Lmax=          136,
 Rint=0.85,RNorm=1.00,NTERM=11,
 ktype=1,Angle=360.,NPTC= 1440,
 npoint=           9 &
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&po x= -6.750000, y=  8.750000 &
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&po x= -3.100000, y=  0.919600 &

&po x= -3.0000, y=  0.9788 &
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***FUDGED****
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***FUDGED****
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***FUDGED****
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***FUDGED****

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7 &   FLUX RET TOP
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 &po x=  5.500000, y=  0.000000 &
 &po x=  6.250000, y=  0.000000 &
 &po x=  6.250000, y=  8.250000 &
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      FLUX RET LEFT
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 &po x= -5.500000, y=  8.250000 &
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 &po x= -6.250000, y=  0.000000 &
 &po x= -6.250000, y=  8.250000 &
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BRICK COMPENSATOR
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 &po x= -3.030000, y=  7.500000 &
 &po x= -3.030000, y=  5.490000 &
 &po x= -3.490000, y=  5.490000 &
 &reg mat=3, npoint=5 &       TOP
BRICK COMPENSATOR
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 &po x=  3.030000, y=  7.500000 &
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BRICK COMPENSATOR
 &po x= -3.490000, y=  5.490000 &
 &po x= -3.490000, y=  5.020000 &
 &po x= -5.500000, y=  5.020000 &
 &po x= -5.500000, y=  5.490000 &
 &po x= -3.490000, y=  5.490000 &
 &reg mat=3, npoint=5 &       SIDE
BRICK COMPENSATOR
 &po x=  3.490000, y=  5.490000 &
 &po x=  3.490000, y=  5.020000 &
 &po x=  5.500000, y=  5.020000 &
 &po x=  5.500000, y=  5.490000 &
 &po x=  3.490000, y=  5.490000 &
 &reg mat=2, npoint=          74 &
      ***MIRROR POLETIP
 &po x= -5.500000, y= -1.750000 &
 &po x= -5.500000, y= -1.000000 &
 &po x= -4.990000, y= -1.000000 &
 &po x= -3.490000, y= -1.375000 &
 &po x= -3.200000, y= -1.375000 &
 &po x= -3.100000, y= -1.375000 &
 &po x= -3.000000, y= -1.375000 &

 &po x= -2.9000, y= -1.3685 &
*****FUDGED******
 &po x= -2.8000, y= -1.3414 &
*****FUDGED******
 &po x= -2.7000, y= -1.2892 &
*****FUDGED******
 &po x= -2.6000, y= -1.2480 &
*****FUDGED******

 &po x= -2.500000, y= -1.241206 &
 &po x= -2.400000, y= -1.227313 &
 &po x= -2.300000, y= -1.207434 &
 &po x= -2.200000, y= -1.184376 &
 &po x= -2.100000, y= -1.161846 &
 &po x= -2.000000, y= -1.143461 &
 &po x= -1.900000, y= -1.131772 &
```

```
&po x= -1.800000, y= -1.124220 &
&po x= -1.700000, y= -1.117181 &
&po x= -1.600000, y= -1.110304 &
&po x= -1.500000, y= -1.103236 &
&po x= -1.400000, y= -1.095719 &
&po x= -1.300000, y= -1.088004 &
&po x= -1.200000, y= -1.080437 &
&po x= -1.100000, y= -1.073015 &
&po x= -1.000000, y= -1.065733 &
&po x= -0.900000, y= -1.058589 &
&po x= -0.800000, y= -1.051580 &
&po x= -0.700000, y= -1.044703 &
&po x= -0.600000, y= -1.037954 &
&po x= -0.500000, y= -1.031330 &
&po x= -0.400000, y= -1.024830 &
&po x= -0.300000, y= -1.018449 &
&po x= -0.200000, y= -1.012186 &
&po x= -0.100000, y= -1.006037 &
&po x=  0.000000, y= -1.000000 &
&po x=  0.100000, y= -0.994072 &
&po x=  0.200000, y= -0.988250 &
&po x=  0.300000, y= -0.982533 &
&po x=  0.400000, y= -0.976917 &
&po x=  0.500000, y= -0.971400 &
&po x=  0.600000, y= -0.965980 &
&po x=  0.700000, y= -0.960654 &
&po x=  0.800000, y= -0.955421 &
&po x=  0.900000, y= -0.950277 &
&po x=  1.000000, y= -0.945220 &
&po x=  1.100000, y= -0.940249 &
&po x=  1.200000, y= -0.935361 &
&po x=  1.300000, y= -0.930554 &
&po x=  1.400000, y= -0.925827 &
&po x=  1.500000, y= -0.921176 &
&po x=  1.600000, y= -0.916600 &
&po x=  1.700000, y= -0.912097 &
&po x=  1.800000, y= -0.907665 &
&po x=  1.900000, y= -0.903302 &
&po x=  2.000000, y= -0.898712 &
 &po x=  2.100000, y= -0.893679 &
 &po x=  2.200000, y= -0.888416 &
 &po x=  2.300000, y= -0.883214 &
 &po x=  2.400000, y= -0.878366 &
 &po x=  2.500000, y= -0.874084 &
 &po x=  2.600000, y= -0.870447 &
 &po x=  2.700000, y= -0.879856 &
 &po x=  2.800000, y= -0.911233 &
 &po x=  2.900000, y= -0.955145 &
 &po x=  3.000000, y= -0.998813 &
 &po x=  3.100000, y= -1.000000 &
 &po x=  3.200000, y= -1.000000 &
 &po x=  3.490000, y= -1.000000 &
 &po x=  3.690000, y= -1.000000 &
 &po x=  5.500000, y= -1.000000 &
 &po x=  5.500000, y= -1.750000 &
 &po x= -5.500000, y= -1.750000 &
 &reg mat=2, npoint=5 & Miror FLUXRET
RIGHT
 &po x=  6.250000, y= -1.750000 &
 &po x=  5.500000, y= -1.750000 &
 &po x=  5.500000, y=  0.000000 &
 &po x=  6.250000, y=  0.000000 &
 &po x=  6.250000, y= -1.750000 &
 &reg mat=2, npoint=5 &  Mirror
FLUXRET LEFT
 &po x= -6.250000, y= -1.750000 &
 &po x= -5.500000, y= -1.750000 &
 &po x= -5.500000, y=  0.000000 &
 &po x= -6.250000, y=  0.000000 &
 &po x= -6.250000, y= -1.750000 &
 &reg mat=1,cur=1., npoint=2  &
PANIDRA CURRENT LINE
 &po x=  3.030000, y=  5.490000 &
 &po x=  3.030000, y=  7.500000 &
 &reg mat=1,cur=1., npoint=2 &
PANIDRA CURRENT LINE
 &po x= -3.030000, y=  7.500000 &
 &po x= -3.030000, y=  5.490000 &
```

Appendix 2 - MGS Mirror Magnet POISSON (PANDIRA) FILE

```
Mirror SF Magnet with hand-Fudged pole
tips for using 3/4" Ball Cutter
 &reg nreg= 17,
 Xmin =   -6.75000 ,
 Xreg1=   -4.10000 , Kreg1= 27,
 Xreg2= 4.10000 , Kreg2=   191,
 Xmax = 6.75000 , Kmax= 218,
 Ymin=   -2.50000 ,
 Yreg1=   -1.80000  Lreg1=  8,
 Yreg2=   0.000000 , Lreg2= 50,
 Yreg3= 2.20000 , Lreg3=   101,
 Ymax= 8.75000 , Lmax= 151,
  Rint=0.85,RNorm=1.00,NTERM=11,
  ktype=1,Angle=360.,NPTC=  1440,
  npoint=  9 &
 &po x= -6.750000, y= -2.500000 &
 &po x= -6.750000, y=  8.750000 &
 &po x=  6.750000, y=  8.750000 &
 &po x=  6.750000, y= -2.500000 &
 &po x=  6.250000, y= -2.500000 &
 &po x=  5.500000, y= -2.500000 &
 &po x= -5.500000, y= -2.500000 &
 &po x= -6.250000, y= -2.500000 &
 &po x= -6.750000, y= -2.500000 &
 &reg mat=2, npoint= 70 &   POLETIP
 &po x= -3.490000, y=  5.490000 &
 &po x= -3.490000, y=  1.020588 &
 &po x= -3.200000, y=  1.020588 &
 &po x= -3.100000, y=  1.020588 &
 &po x= -3.000000, y=  1.145185 &
 &po x= -2.900000, y=  1.394574 &
 &po x= -2.800, y=  1.707 &
 &po x= -2.700, y=  1.803 &
 &po x= -2.600, y=  1.848 &
 &po x= -2.500, y=  1.863 &
 &po x= -2.400, y=  1.851 &
 &po x= -2.300, y=  1.808 &
 &po x= -2.200, y=  1.719 &
 &po x= -2.100000, y=  1.512809 &
 &po x= -2.000000, y=  1.390604 &
 &po x= -1.900000, y=  1.330223 &
 &po x= -1.800000, y=  1.306000 &
 &po x= -1.700000, y=  1.282939 &
 &po x= -1.600000, y=  1.260934 &
 &po x= -1.500000, y=  1.239894 &
 &po x= -1.400000, y=  1.219734 &
 &po x= -1.300000, y=  1.200383 &
 &po x= -1.200000, y=  1.181772 &
 &po x= -1.100000, y=  1.163845 &
 &po x= -1.000000, y=  1.146548 &
 &po x= -0.900000, y=  1.129834 &
 &po x= -0.800000, y=  1.113662 &
 &po x= -0.700000, y=  1.097994 &
 &po x= -0.600000, y=  1.082796 &
 &po x= -0.500000, y=  1.068038 &
 &po x= -0.400000, y=  1.053693 &
 &po x= -0.300000, y=  1.039737 &
 &po x= -0.200000, y=  1.026148 &
 &po x= -0.100000, y=  1.012908 &
 &po x=  0.000000, y=  1.000000 &
 &po x=  0.100000, y=  0.987408 &
 &po x=  0.200000, y=  0.975119 &
 &po x=  0.300000, y=  0.963121 &
 &po x=  0.400000, y=  0.951404 &
 &po x=  0.500000, y=  0.939959 &
 &po x=  0.600000, y=  0.928778 &
 &po x=  0.700000, y=  0.917853 &
 &po x=  0.800000, y=  0.907179 &
 &po x=  0.900000, y=  0.896751 &
 &po x=  1.000000, y=  0.886564 &
 &po x=  1.100000, y=  0.876616 &
 &po x=  1.200000, y=  0.866901 &
 &po x=  1.300000, y=  0.857419 &
 &po x=  1.400000, y=  0.848168 &
 &po x=  1.500000, y=  0.839146 &
 &po x=  1.600000, y=  0.830351 &
 &po x=  1.700000, y=  0.821784 &
 &po x=  1.800000, y=  0.813444 &
 &po x=  1.900000, y=  0.805331 &
 &po x=  2.000000, y=  0.797446 &
 &po x=  2.100000, y=  0.789790 &
 &po x=  2.200000, y=  0.782362 &
 &po x=  2.300000, y=  0.775166 &
 &po x=  2.400000, y=  0.768202 &
 &po x=  2.500000, y=  0.761472 &
 &po x=  2.600000, y=  0.754978 &
 &po x=  2.700000, y=  0.743534 &
 &po x=  2.800000, y=  0.723344 &
 &po x=  2.900000, y=  0.698210 &
 &po x=  3.000000, y=  0.673323 &
 &po x=  3.100000, y=  0.653876 &
 &po x=  3.200000, y=  0.643669 &
 &po x=  3.490000, y=  0.643669 &
 &po x=  3.490000, y=  5.490000 &
 &po x= -3.490000, y=  5.490000 &
 &reg mat=  7, npoint=5 &   RIGHT
SIDE BRICK  0
 &po x=  3.490000, y=  1.300000 &
```

```
 &po x=  5.500000, y=  1.300000 &
 &po x=  5.500000, y=  5.020000 &
 &po x=  3.490000, y=  5.020000 &
 &po x=  3.490000, y=  1.300000 &
 &reg mat=  8, npoint=5 &   LEFT SIDE
BRICK  0
 &po x= -3.490000, y=  1.300000 &
 &po x= -5.500000, y=  1.300000 &
 &po x= -5.500000, y=  5.020000 &
 &po x= -3.490000, y=  5.020000 &
 &po x= -3.490000, y=  1.300000 &
 &reg mat=  6, npoint=5 &   TOP BRICK
0
 &po x= -3.030000, y=  5.490000 &
 &po x= -3.030000, y=  7.500000 &
 &po x=  3.030000, y=  7.500000 &
 &po x=  3.030000, y=  5.490000 &
 &po x= -3.030000, y=  5.490000 &
 &reg mat=  2, npoint=  7 &  FLUX RET
TOP
 &po x=  5.500000, y=  8.250000 &
 &po x= -5.500000, y=  8.250000 &
 &po x= -5.500000, y=  7.500000 &
 &po x= -3.030000, y=  7.500000 &
 &po x=  3.030000, y=  7.500000 &
 &po x=  5.500000, y=  7.500000 &
 &po x=  5.500000, y=  8.250000 &
 &reg mat=2, npoint=5 &   FLUX RET
RIGHT SIDE
 &po x=  6.250000, y=  8.250000 &
 &po x=  5.500000, y=  8.250000 &
 &po x=  5.500000, y=  0.000000 &
 &po x=  6.250000, y=  0.000000 &
 &po x=  6.250000, y=  8.250000 &
 &reg mat=2, npoint=5 &   FLUX RET
LEFT
 &po x= -6.250000, y=  8.250000 &
 &po x= -5.500000, y=  8.250000 &
 &po x= -5.500000, y=  0.000000 &
 &po x= -6.250000, y=  0.000000 &
 &po x= -6.250000, y=  8.250000 &
 &reg mat=3, npoint=5 &  TOP BRICK
COMPENSATOR
 &po x= -3.490000, y=  5.490000 &
 &po x= -3.490000, y=  7.500000 &
 &po x= -3.030000, y=  7.500000 &
 &po x= -3.030000, y=  5.490000 &
 &po x= -3.490000, y=  5.490000 &
 &reg mat=3, npoint=5 &  TOP BRICK
COMPENSATOR
 &po x=  3.490000, y=  5.490000 &
 &po x=  3.490000, y=  7.500000 &
 &po x=  3.030000, y=  7.500000 &
 &po x=  3.030000, y=  5.490000 &
 &po x=  3.490000, y=  5.490000 &
 &reg mat=3, npoint=5 &  SIDE BRICK
COMPENSATOR
 &po x= -3.490000, y=  5.490000 &
 &po x= -3.490000, y=  5.020000 &
 &po x= -5.500000, y=  5.020000 &
 &po x= -5.500000, y=  5.490000 &
 &po x= -3.490000, y=  5.490000 &
 &reg mat=3, npoint=5 &  SIDE BRICK
COMPENSATOR
 &po x=  3.490000, y=  5.490000 &
 &po x=  3.490000, y=  5.020000 &
 &po x=  5.500000, y=  5.020000 &
 &po x=  5.500000, y=  5.490000 &
 &po x=  3.490000, y=  5.490000 &
 &reg mat=2, npoint= 78 &   ***MIRROR
POLETIP
 &po x= -5.500000, y= -2.000000 &
 &po x= -5.500000, y= -1.250000 &
 &po x= -4.990000, y= -1.250000 &
 &po x= -3.490000, y= -1.625000 &
 &po x= -3.200000, y= -1.625000 &
 &po x= -3.100000, y= -1.625000 &
 &po x= -3.000000, y= -1.625000 &
 &po x= -2.900000, y= -1.625000 &
 &po x= -2.800000, y= -1.625000 &
 &po x= -2.700000, y= -1.625000 &
 &po x= -2.600000, y= -1.625000 &
 &po x= -2.500000, y= -1.625000 &
 &po x= -2.400000, y= -1.625000 &
 &po x= -2.300, y= -1.621 &
 &po x= -2.200, y= -1.591 &
 &po x= -2.100, y= -1.525 &
 &po x= -2.000000, y= -1.405979 &
 &po x= -1.900000, y= -1.344340 &
 &po x= -1.800000, y= -1.318253 &
 &po x= -1.700000, y= -1.289549 &
 &po x= -1.600000, y= -1.261013 &
 &po x= -1.500000, y= -1.235420 &
 &po x= -1.400000, y= -1.214809 &
 &po x= -1.300000, y= -1.197209 &
 &po x= -1.200000, y= -1.179913 &
 &po x= -1.100000, y= -1.162942 &
 &po x= -1.000000, y= -1.146310 &
 &po x= -0.900000, y= -1.130032 &
 &po x= -0.800000, y= -1.114115 &
 &po x= -0.700000, y= -1.098566 &
 &po x= -0.600000, y= -1.083388 &
 &po x= -0.500000, y= -1.068581 &
 &po x= -0.400000, y= -1.054143 &
 &po x= -0.300000, y= -1.040072 &
 &po x= -0.200000, y= -1.026362 &
 &po x= -0.100000, y= -1.013007 &
 &po x=  0.000000, y= -1.000000 &
 &po x=  0.100000, y= -0.987332 &
 &po x=  0.200000, y= -0.974993 &
 &po x=  0.300000, y= -0.962973 &
 &po x=  0.400000, y= -0.951263 &
 &po x=  0.500000, y= -0.939849 &
 &po x=  0.600000, y= -0.928721 &
```

```
&po x=  0.700000, y= -0.917866 &
&po x=  0.800000, y= -0.907273 &
&po x=  0.900000, y= -0.896928 &
&po x=  1.000000, y= -0.886819 &
&po x=  1.100000, y= -0.876933 &
&po x=  1.200000, y= -0.867257 &
&po x=  1.300000, y= -0.857778 &
&po x=  1.400000, y= -0.848484 &
&po x=  1.500000, y= -0.839361 &
&po x=  1.600000, y= -0.830396 &
&po x=  1.700000, y= -0.821578 &
&po x=  1.800000, y= -0.812892 &
&po x=  1.900000, y= -0.804328 &
&po x=  2.000000, y= -0.795872 &
&po x=  2.100000, y= -0.787512 &
&po x=  2.200000, y= -0.779237 &
&po x=  2.300000, y= -0.771035 &
&po x=  2.400000, y= -0.762895 &
&po x=  2.500000, y= -0.754805 &
&po x=  2.600000, y= -0.746755 &
&po x=  2.700000, y= -0.744408 &
&po x=  2.800000, y= -0.751906 &
&po x=  2.900000, y= -0.765087 &
&po x=  3.000000, y= -0.778269 &
&po x=  3.100000, y= -0.785769 &
&po x=  3.200000, y= -0.783427 &
&po x=  3.490000, y= -0.783427 &
&po x=  3.590, y= -1.016 &
&po x=  3.690, y= -1.157 &
 &po x=  3.790, y= -1.220 &
 &po x=  3.890, y= -1.247 &
 &po x=  3.990, y= -1.250 &
 &po x=  5.500000, y= -1.250000 &
 &po x=  5.500000, y= -2.000000 &
 &po x= -5.500000, y= -2.000000 &
 &reg mat=2, npoint=5 & Miror FLUXRET
RIGHT
 &po x=  6.250000, y= -2.000000 &
 &po x=  5.500000, y= -2.000000 &
 &po x=  5.500000, y=  0.000000 &
 &po x=  6.250000, y=  0.000000 &
 &po x=  6.250000, y= -2.000000 &
 &reg mat=2, npoint=5 &  Mirror
FLUXRET LEFT
 &po x= -6.250000, y= -2.000000 &
 &po x= -5.500000, y= -2.000000 &
 &po x= -5.500000, y=  0.000000 &
 &po x= -6.250000, y=  0.000000 &
 &po x= -6.250000, y= -2.000000 &
 &reg mat=1,cur=1., npoint=2  &
PANIDRA CURRENT LINE
 &po x=  3.030000, y=  5.490000 &
 &po x=  3.030000, y=  7.500000 &
 &reg mat=1,cur=1., npoint=2 &
PANIDRA CURRENT LINE
 &po x= -3.030000, y=  7.500000 &
 &po x= -3.030000, y=  5.490000 &
```

Appendix 3 - MDA Mirror Magnet POISSON (PANDIRA) FILE

```
Recycler Abort Mirror Magnet
 &reg nreg= 17,
 Xmin =   -6.75000 ,
 Xreg1=   -4.10000 , Kreg1= 13,
 Xreg2= 4.10000 , Kreg2= 95,
 Xmax = 6.75000 , Kmax= 108,
 Ymin=   -2.25000 ,
 Yreg1=   -1.55000  Lreg1=  4,
 Yreg2=   0.000000 , Lreg2= 22,
 Yreg3= 1.60000 , Lreg3= 40,
 Ymax= 8.75000 , Lmax=  68,
  Rint=0.85,RNorm=1.00,NTERM=11,
  ktype=1,Angle=360.,NPTC=  1440,
  npoint=  9 &
 &po x= -6.750000, y= -2.250000 &
 &po x= -6.750000, y=  8.750000 &
 &po x=  6.750000, y=  8.750000 &
 &po x=  6.750000, y= -2.250000 &
 &po x=  6.250000, y= -2.250000 &
 &po x=  5.500000, y= -2.250000 &
 &po x= -5.500000, y= -2.250000 &
 &po x= -6.250000, y= -2.250000 &
 &po x= -6.750000, y= -2.250000 &
 &reg mat=2, npoint= 12 & POLETIP
 &po x= -3.490000, y=  5.490000 &
 &po x= -3.490000, y=  0.758000 &
 &po x= -2.990000, y=  0.758000 &
 &po x= -2.990000, y=  1.000000 &
 &po x= -1.000000, y=  1.000050 &
 &po x=  0.000000, y=  1.000000 &
 &po x=  1.000000, y=  0.999950 &
 &po x=  2.990000, y=  1.000000 &
 &po x=  2.990000, y=  0.758000 &
 &po x=  3.490000, y=  0.758000 &
 &po x=  3.490000, y=  5.490000 &
 &po x= -3.490000, y=  5.490000 &
 &reg mat=  7, npoint=5 &   RIGHT SIDE
BRICK  0
 &po x=  3.490000, y=  1.000000 &
 &po x=  5.500000, y=  1.000000 &
 &po x=  5.500000, y=  5.020000 &
 &po x=  3.490000, y=  5.020000 &
 &po x=  3.490000, y=  1.000000 &
 &reg mat=  8, npoint=5 &   LEFT SIDE BRICK
0
 &po x= -3.490000, y=  1.000000 &
 &po x= -5.500000, y=  1.000000 &
 &po x= -5.500000, y=  5.020000 &
 &po x= -3.490000, y=  5.020000 &
 &po x= -3.490000, y=  1.000000 &
 &reg mat=  6, npoint=5 &   TOP BRICK  0
 &po x= -3.030000, y=  5.490000 &
 &po x= -3.030000, y=  7.500000 &
 &po x=  3.030000, y=  7.500000 &
 &po x=  3.030000, y=  5.490000 &
 &po x= -3.030000, y=  5.490000 &
 &reg mat=  2, npoint=  7 &  FLUX RET TOP
 &po x=  5.500000, y=  8.250000 &
 &po x= -5.500000, y=  8.250000 &
 &po x= -5.500000, y=  7.500000 &
 &po x= -3.030000, y=  7.500000 &
 &po x=  3.030000, y=  7.500000 &
 &po x=  5.500000, y=  7.500000 &
 &po x=  5.500000, y=  8.250000 &
 &reg mat=2, npoint=5 &   FLUX RET RIGHT
SIDE
 &po x=  6.250000, y=  8.250000 &
 &po x=  5.500000, y=  8.250000 &
 &po x=  5.500000, y=  0.000000 &
 &po x=  6.250000, y=  0.000000 &
 &po x=  6.250000, y=  8.250000 &
 &reg mat=2, npoint=5 &   FLUX RET LEFT
 &po x= -6.250000, y=  8.250000 &
 &po x= -5.500000, y=  8.250000 &
 &po x= -5.500000, y=  0.000000 &
 &po x= -6.250000, y=  0.000000 &
 &po x= -6.250000, y=  8.250000 &
 &reg mat=3, npoint=5 &  TOP BRICK
COMPENSATOR
 &po x= -3.490000, y=  5.490000 &
 &po x= -3.490000, y=  7.500000 &
 &po x= -3.030000, y=  7.500000 &
 &po x= -3.030000, y=  5.490000 &
 &po x= -3.490000, y=  5.490000 &
 &reg mat=3, npoint=5 &  TOP BRICK
COMPENSATOR
 &po x=  3.490000, y=  5.490000 &
 &po x=  3.490000, y=  7.500000 &
 &po x=  3.030000, y=  7.500000 &
 &po x=  3.030000, y=  5.490000 &
 &po x=  3.490000, y=  5.490000 &
 &reg mat=3, npoint=5 &  SIDE BRICK
COMPENSATOR
 &po x= -3.490000, y=  5.490000 &
 &po x= -3.490000, y=  5.020000 &
 &po x= -5.500000, y=  5.020000 &
 &po x= -5.500000, y=  5.490000 &
 &po x= -3.490000, y=  5.490000 &
 &reg mat=3, npoint=5 &  SIDE BRICK
COMPENSATOR
 &po x=  3.490000, y=  5.490000 &
 &po x=  3.490000, y=  5.020000 &
 &po x=  5.500000, y=  5.020000 &
 &po x=  5.500000, y=  5.490000 &
 &po x=  3.490000, y=  5.490000 &
 &reg mat=2, npoint= 12 &   ***MIRROR
POLETIP
 &po x= -5.500000, y= -1.750000 &
 &po x= -5.500000, y= -1.000000 &
 &po x= -4.990000, y= -1.000000 &
```

```
 &po x= -3.490000, y= -1.000000 &
 &po x= -1.000000, y= -1.000000 &
 &po x=  0.000000, y= -1.000000 &
 &po x=  1.000000, y= -1.000000 &
 &po x=  3.490000, y= -1.000000 &
 &po x=  3.690000, y= -1.000000 &
 &po x=  5.500000, y= -1.000000 &
 &po x=  5.500000, y= -1.750000 &
 &po x= -5.500000, y= -1.750000 &
 &reg mat=2, npoint=5 & Miror FLUXRET RIGHT
 &po x=  6.250000, y= -1.750000 &
 &po x=  5.500000, y= -1.750000 &
 &po x=  5.500000, y=  0.000000 &
 &po x=  6.250000, y=  0.000000 &
 &po x=  6.250000, y= -1.750000 &
 &reg mat=2, npoint=5 &  Mirror FLUXRET
LEFT
 &po x= -6.250000, y= -1.750000 &
 &po x= -5.500000, y= -1.750000 &
 &po x= -5.500000, y=  0.000000 &
 &po x= -6.250000, y=  0.000000 &
 &po x= -6.250000, y= -1.750000 &
 &reg mat=1,cur=1., npoint=2  & PANIDRA
CURRENT LINE
 &po x=  3.030000, y=  5.490000 &
 &po x=  3.030000, y=  7.500000 &
 &reg mat=1,cur=1., npoint=2 & PANIDRA
CURRENT LINE
 &po x= -3.030000, y=  7.500000 &
 &po x= -3.030000, y=  5.490000 &
```