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MAGNETIC FIELD OF A TOROIDAL VOLUME H⁻ SOURCE

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INFORMAL REPORT

ALTERNATING GRADIENT SYNCHROTRON DEPARTMENT

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Abstract

A volume H^- source has been constructed by Prelec¹ at BNL. The magnetic field for this source has been calculated using the computer code PANDIRA. A comparison of the magnetic fields for two cases is presented.

Introduction

One method of producing H^- for injection into the AGS Linac is by the volume production method described by Bacal and Bruneteau². Subsequent work by Prelec¹ has resulted in a volume source that has toroidal symmetry, with the beam extracted along the axis. This device has shown that the extracted current is sensitive to the field created by a permanent magnet located on axis opposite the extraction aperture. Presumably, this dipole moment of the field acts in a manner similar to the filter fields used in tandem multicusp sources³: the higher magnetic field prevents fast electrons produced by the filament from reaching the region where H^- production occurs, while thermal electrons are allowed to diffuse into the production zone.

A detailed knowledge of the source's magnetic field would allow one to understand the relationship between the position of the magnet creating the dipole field component on axis and the extracted electron and H^- currents. To this end, a set of magnetic field calculations was performed in order to examine the shape of the field with different magnet configurations. In particular, an attempt was made to examine the changes in the structure of the field close to the axis when the dipole magnet was introduced.

Input for the calculation

The input geometry was obtained by scaling directly from the assembly drawing of the source, Figure 1. A sample data file for use with AUTOMESH is listed in Appendix A. All dimensions are in centimeters with "X" corresponding to the radius from the central axis, and "Y" corresponding to length along the axis. The coordinate system is indicated in Figure 1.

The magnetic properties of the iron and permanent magnets were needed for the actual PANDIRA run. PANDIRA possesses an internal B-H curve for iron, which was used for these calculations. The B-H curves for the permanent magnets were taken from the data for Tascore-18⁴ Sm-Co magnets supplied by the manufacturer. Since PANDIRA assumes a linear dependence of B on H, only the residual induction, B_r , and the coercive force, H_c , were needed. The residual induction for Tascore-18 is 8600 Gauss, and the coercive force is -8400 Oe. The recoil permeability is 1.05, and was assumed to be 1.0 in the calculation.

Field Calculations

Each calculation consisted of three separate phases. First, the input file to PANDIRA was created by running AUTOMESH and then LATTICE. The output of lattice was then used by PANDIRA to perform the actual magnetic field calculations. Finally, the output of PANDIRA was processed by either TEKDIS, to create a plot of the field lines, or by VOL_B_FLD_CONTOUR (see Appendix B) to provide a contour plot of the total magnetic field.

Three separate cases were considered. First, the magnetic field for the source was calculated using only the cusp rings of permanent magnets. The effective radial thickness of the magnet rings, which were built by assembling the required number of 0.63 cm diameter rod magnets, was determined such that the transverse cross-sectional area of the physical magnets was equal to the area of the model ring. The model width of a magnet ring is 0.55 cm compared to the actual physical diameter of an individual magnet of 0.63 cm. The longitudinal extent of the physical and model magnets were identical at 1.3 cm. Second, a 2.5 cm diameter, 1 cm thick disk of Tascore-18 was added in the center of the filament flange and the magnetic field was recalculated. Finally, the position of the disk was varied to examine the effect of the position on the field in the region around the axis. A harmonic analysis of the field in the R-Z plane was performed at each disk position by PANDIRA.

Results and Discussion

The results of a calculation of the entire magnetic field without the dipole magnet on axis are shown in Figure 2. Figure 2a shows the field lines produced by TEKDIS, while Figure 2b shows a contour plot of the total magnetic field. Figure 3 shows a longitudinal scan of the field at several radii. The beginning and end of curves in Figure 3 correspond to the inside of the copper vacuum chamber.

The results of a calculation similar to the one described above, except that a dipole field magnet has been added, are shown in Figures 4a and 4b. The dipole magnet was 2.5 cm diameter, 1 cm thick, and the distance between the plasma electrode and magnet face was 4.7 cm. The "dipole cone" is immediately seen in Figure 4a. The total magnetic field shows a corresponding distortion due to this magnet.

The field expansion used by the POISSON/PANDIRA⁵ harmonic analysis module is

$$B_R - i B_Z = i \sum_n \frac{n (a_n + i b_n)}{R} \left(\frac{\rho}{R} \right)^{n-1}$$

where a_n and b_n are determined by Fourier analysis of the vector potential on a circle of radius R , and ρ is a complex variable representation of the position, $\rho = R + iz$. Figure 5 shows the geometry of the calculation. The calculated dipole components of the magnetic field in the region of the extraction aperture are shown in Figure 6. Both of the coefficients are non-zero which indicates that there are simultaneously regular and skew dipole moments. This is a consequence of the axial symmetry of the field and that the "dipole" field close to the axis is conical. Table I lists the multipole moments up to $n=10$ when the plasma electrode-magnet face separation is 5.55 cm. For each component both regular and skew multipoles are present.

Conclusion

The magnetic field for a toroidal multicusp volume source has been calculated using PANDIRA. The presence of a permanent magnet on axis creates a region around the axis where a large dipole moment exists. This field provides an effective shield of the extraction region from high energy electrons emitted by the source filament.

Acknowledgement

I would like to thank Krsto Prelec for suggesting that I undertake these calculations and for several interesting conversations concerning the details of his source.

References

1. K. Prelec, "A Volume H^- Ion Source with a Toroidal Discharge Chamber", BNL-41849 and to be published in Proceedings of the 1989 Particle Accelerator Conference, Chicago IL, March 1989.
2. M. Bacal and A.M. Bruneteau, Proc. 3rd Int. Symp. on the Production and Neutralization of Negative Ions and Beams, (Brookhaven National Laboratory, 1983) ed. Krsto Prelec, AIP Conf Proc. No. 111 (1984) 31.
3. J.R. Hiskes, Proc. 4th Int. Symp. on the Production and Neutralization of Negative Ions and Beams (Brookhaven National Laboratory, 1986) ed. James G. Alessi, AIP Conf. Proc. No. 158 (1987) 2.
4. Thomas and Skinner, Inc., 1120 E. 23rd Street, P.O. Box 150-B, Indianapolis, IN 46206.
5. POISSON/SUPERFISH Reference Manual, LA-UR-87-126, Part B, Chapter 13, Section 3, pp. 45-51.

Table I

N	N(AN)/R	N(BN)/R	ABS(N[CN])/R
1	-1.9173E+01	-8.5742E+00	2.1003E+01
2	-6.3736E+00	-3.0322E+01	3.0974E+01
3	-3.9230E+00	-1.3103E+01	1.3677E+01
4	-2.0708E+00	-1.2355E+01	1.2527E+01
5	5.983E4E-01	-1.0842E+00	1.2384E+00
6	-9.7910E-01	-1.0582E+00	1.4417E+00
7	-1.1828E-01	2.2141E-01	2.5102E-01
8	-1.4065E-01	-3.7861E-01	4.0389E-01
9	3.6554E-02	1.7491E-01	1.7869E-01
10	-1.1312E-02	-1.0768E-01	1.0828E-01

Appendix A: Automesh Input for Configuration 2

Volume H- Source: Conf. 2

\$REG NREG=17, DX=.1, DY=.15, YMAX=10.25, XMAX=13.9,
XMIN=0., YMIN=0., NPOINT=5, MAT=1 \$

\$PO Y=0., X=0. \$

\$PO Y=10.25, X=0. \$

\$PO Y=10.25, X=13.9 \$

\$PO Y=0., X=13.9 \$

\$PO Y=0., X=0. \$

\$REG IREG=2, NPOINT=7, MAT=2 \$

\$PO Y=0., X=3.35 \$

\$PO Y=0., X=11.1 \$

\$PO Y=1.8, X=11.1 \$

\$PO Y=1.8, X=10.3 \$

\$PO Y=0.5, X=10.3 \$

\$PO Y=0.5, X=3.35 \$

\$PO Y=0., X=3.35 \$

\$REG IREG=3, NPOINT=5, MAT=6 \$

\$PO Y=0.5, X=3.55 \$

\$PO Y=0.5, X=4.1 \$

\$PO Y=1.8, X=4.1 \$

\$PO Y=1.8, X=3.55 \$

\$PO Y=0.5, X=3.55 \$

\$REG IREG=4, NPOINT=5, MAT=7 \$

\$PO Y=8.45, X=3.55 \$

\$PO Y=8.45, X=4.1 \$

\$PO Y=9.75, X=4.1 \$

\$PO Y=9.75, X=3.55 \$

\$PO Y=8.45, X=3.55 \$

\$REG IREG=5, NPOINT=5, MAT=7 \$

\$PO Y=0.5, X=5.5 \$

\$PO Y=0.5, X=6.05 \$

\$PO Y=1.8, X=6.05 \$

\$PO Y=1.8, X=5.5 \$

\$PO Y=0.5, X=5.5 \$

\$REG IREG=6, NPOINT=5, MAT=6 \$

\$PO Y=8.45, X=5.5 \$

\$PO Y=8.45, X=6.05 \$

\$PO Y=9.75, X=6.05 \$

\$PO Y=9.75, X=5.5 \$

\$PO Y=8.45, X=5.5 \$

\$REG IREG=7, NPOINT=5, MAT=6 \$

\$PO Y=1.8, X=7.4 \$

\$PO Y=0.5, X=7.4 \$

\$PO Y=0.5, X=7.95 \$

\$PO Y=1.8, X=7.95 \$

\$PO Y=1.8, X=7.4 \$

\$REG IREG=8, NPOINT=5, MAT=7 \$

\$PO Y=9.75, X=7.4 \$

\$PO Y=8.45, X=7.4 \$

\$PO Y=8.45, X=7.95 \$

\$PO Y=9.75, X=7.95 \$

```

$PO Y=9.75, X=7.4 $
$REG IREG=9, NPOINT=5, MAT=7 $
$PO Y=0.5, X=9.35 $
$PO Y=1.8, X=9.35 $
$PO Y=1.8, X=9.9 $
$PO Y=0.5, X=9.9 $
$PO Y=0.5, X=9.35 $
$REG IREG=10, NPOINT=5, MAT=6 $
$PO Y=8.45, X=9.35 $
$PO Y=9.75, X=9.35 $
$PO Y=9.75, X=9.9 $
$PO Y=8.45, X=9.9 $
$PO Y=8.45, X=9.35 $
$REG IREG=11, NPOINT=2, CUR=1000., MAT=1 $
$PO Y=1.8, X=3.55 $
$PO Y=1.8, X=4.1 $
$REG IREG=12, NPOINT=7, MAT=2 $
$PO Y=10.25, X=3.35 $
$PO Y=10.25, X=12.0 $
$PO Y=8.45, X=12.0 $
$PO Y=8.45, X=11.2 $
$PO Y=9.75, X=11.2 $
$PO Y=9.75, X=3.35 $
$PO Y=10.25, X=3.35 $
$REG IREG=13, NPOINT=9, MAT=2 $
$PO Y=2.5, X=12.0 $
$PO Y=2.5, X=13.9 $
$PO Y=3.1, X=13.9 $
$PO Y=3.1, X=12.75 $
$PO Y=6.75, X=12.75 $
$PO Y=6.75, X=13.7 $
$PO Y=7.4, X=13.7 $
$PO Y=7.4, X=12.0 $
$PO Y=2.5, X=12.0 $
$REG IREG=14, NPOINT=5, MAT=8 $
$PO Y=2.9, X=10.7 $
$PO Y=2.9, X=12.0 $
$PO Y=3.45, X=12.0 $
$PO Y=3.45, X=10.7 $
$PO Y=2.9, X=10.7 $
$REG IREG=15, NPOINT=5, MAT=9 $
$PO Y=4.80, X=10.7 $
$PO Y=4.80, X=12.0 $
$PO Y=5.35, X=12.0 $
$PO Y=5.35, X=10.7 $
$PO Y=4.80, X=10.7 $
$REG IREG=16, NPOINT=5, MAT=8 $
$PO Y=6.70, X=10.7 $
$PO Y=6.70, X=12.0 $
$PO Y=7.25, X=12.0 $
$PO Y=7.25, X=10.7 $
$PO Y=6.70, X=10.7 $
$REG IREG=17, NPOINT=5, MAT=6 $
$PO Y=7.0, X=0.0 $

```

\$PO Y=8.0, X=0.0 \$
\$PO Y=8.0, X=1.3 \$
\$PO Y=7.0, X=1.3 \$
\$PO Y=7.0, X=0.0 \$

Appendix B: The VOL_B_FLD_CONTOUR Program

VOL_B_FLD_CONTOUR is a fortran program on the AMD VAX cluster (clusters 3 or 6) which was written to process output from PANDIRA and generate a contour plot of the total magnetic field.

The initial steps toward using this program are as follows. The first step is to declare CON(45)=71 (this is the value of LMAX) in the input to PANDIRA. This results in the fields and gradients at all mesh points being written to the file OUTPAN.LIS. Next, OUTPAN.LIS is copied to B_PROC.INP and the program B_PROC is called to provide some initial processing of the file. The output of B_PROC is edited to remove approximately 200 lines of extraneous data that passes through the B_PROC filter due to the lines having the same format as the field data. A sample .COM file to partially automate this procedure is included as Figure B-1.

The input to VOL_B_FLD_CONTOUR consists of three different files:

- 1) VOL_B_FLD_CONTOUR.COM -- contains values for the control variables needed by the program,
- 2) VOL_B_FLD.INP -- contains r,z, and B values for each mesh point,
- 3) VOL_B_GEO.DAT -- contains the magnet and iron region data in a form similar to the input for AUTOMESH.

The exact form of each file is readily available from the program listing.

Figure 1 Sketch of source configuration used in this study. The magnets and iron return paths are seen outside the copper vacuum vessel that contains the source plasma.

Figure 2a Magnetic field of "Configuration 1" which did not have a permanent magnet on axis. Field lines produced by TEKDIS.

Figure 2b Magnetic field of "Configuration 1" which did not have a permanent magnet on axis. Contour plot of total magnetic field.

Figure 3 Longitudinal variation of the magnetic field of Configuration 1 at several distances from the axis.

Figure 4a Magnetic field of "Configuration 2" which had a 1 cm thick, 2.5 cm diameter magnet located on the source axis. Field lines produced by TEKDIS.

Figure 4b Magnetic field of "Configuration 2" which had a 1 cm thick, 2.5 cm diameter magnet located on the source axis. Contour plot of total magnetic field.

Symmetry Axis

Circle of Integration

$\vec{B}$

Figure 5 Magnetic field and integration used in the harmonic analysis of the field close to the axis.

Figure 6 Dipole component of the field close to the axis of the source. The regular component strengths are given by a_1 , while the skew components come from b_1 .