DESIGN, FABRICATION AND TESTING OF A NESTED PAIR OF "COS θ DIPOLE" X-Y STEERING MAGNETS

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ABSTRACT

A "Cos θ" steering magnet has been designed, fabricated and installed in the ECR beam line of the K800 superconducting cyclotron at M.S.U. The "Cost θ design" was chosen because two concentric coils could be wound to make an X-Y steering magnet with small component of higher order multipoles.

A "Cos θ" is a magnet in which the current or winding distribution varies as Cos θ of the azimuthal angle. 'POISSON' code was used for the design. The magnetic field at the centre of the dipole is $\sim$58 Gauses. So far as the field uniformity at the magnet Centre was concerned, it was found that the field uniformity was better than 1.5% upto distance of 2". In the case of the outer coil, the field uniformity was better than 1% upto distance of 1.0" and better than 2% upto a distance of 1.5 from the centre. Details of the design and field data obtained with the NSCL X-Y mapper has been presented in paper.

INTRODUCTION

The aim of the project was to design and construct a new type of air-core steering magnet for the ECR axial injection line of the K800 cyclotron. This magnet is mounted above the last bending magnet and directly below the K800 cyclotron and serves as a fine tuning device after the 90 degree magnet bends the beam upward into the K800 axial line.

Steel-core steering magnets[1] are in use in the ECR-K800 beamline. The purpose of this project was to design and construct air-core magnets having uniformity similar to the steel-core ones. The Cos θ type design was chosen because two concentric coils could be wound to make an xy steering magnet with small components of higher-order multipoles[2].

In a simple approximation to the "cosθ - dipole" with two separate blocks (separated by an angle) one can eliminate $N = 3,5,7$ ($2N$ = number of multipolarity).[3] Figure 1 shows schematically the design of a 2-block dipole having outer radius, r_2, inner radius, r_1, constant current desnity, J, and the angles subtended by the blocks, ϕ_1, ϕ_2 and ϕ_3.

THE AMPERE-TURN REQUIREMENTS OF THE MAGNET

The magnet is required to produce a dipole field -60G. The beam pipe has an O.D. of 8", hence r_1 and r_2 were chosen to be 4.0" and 4.25", respectively. Magnetic field computations were done using the POISSON code to find the optimum design parameters.

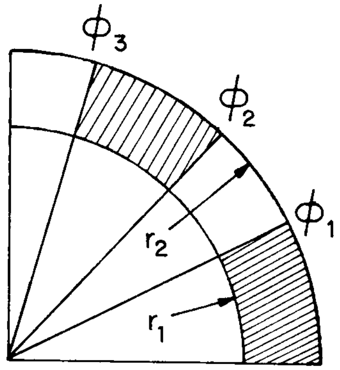

Fig.1 : Schematic diagram of a 2-block 'cosθ' dipole (4-fold symmetry, not to scale).

Because of space limitation and in order to have both x and y steering at the same place it was decided that both x and y magnets would be mounted co-axially, one around the other rotated by 90 degrees. For the outer coil r_1 and r_2 were chosen to be 4.25" and 4.50", respectively.

Various NI (NI = Ampere turn, N = No. of turns, I = Current) values were tried. With NI = 1000 for the inner coil and NI = 1200 for the outer coil, the magnetic fields at the median plane were found to be $\sim$58 Gauss.

Tables I and II show the magnetic field distribution in the median plane up to 2" from the center of the dipole and the higher harmonic contribution for inner and outer coils, respectively. These are the results of POISSON calculations for infinitely-long coils. Also indicated are the calculated fields due to the dipole and first three allowed multipole components.

FABRICATION OF COIL

Physical dimensions of the dipoles are given in Table III. The coil winding fixtures were machined from co-axial cylindrical shells of carbon steel. The coils were wound from 14AWG enamelled copper wire. The number of turns in the 43° and 15° blocks were decided in the ratio 43:15 so that the numbers of turns wound were 148 and 52 respectively. After winding , the coils were brushed with an epoxy mixture of 40% versamid 140 and 60% EPON 815 by weight. The epoxy was cured for four hours in a furnace at 200°C.

Table I

X (in inches)	BTOTAL (Gauss)
0.0	57.124
0.256	57.123
0.512	57.122
0.768	57.120
1.025	57.117
1.281	57.112
1.537	57.104
1.793	57.092
2.050	57.072

N	Field at 2" radius
1	57.124
3	$2.276\text{x}10^{-2}$
5	$1.408\text{x}10^{-2}$
7	$6.327\text{x}10^{-3}$

Table II

X (inches)	BTOTAL (Gauss)
0.0	58.479
0.255	58.479
0.510	58.479
0.765	58.480
1.020	58.481
1.275	58.481
1.530	58.482
1.785	58.482
2.040	58.480

N	Field at 2" radius
1	58.479
3	$7.1644\text{x}10^{-3}$
5	$3.4202\text{x}10^{-3}$
7	$1.654\text{x}10^{-3}$

MAGNETIC FIELD DATA

The magnetic fields in the steering magnets were measured with the NSCL X-Y mapper using a Hall probe with stability better than 1%.

The absolute magnetic field at the center of the magnet, near the effective edge, and the $\int B.dl$ along the central trajectory and two trajectories 2" away from the central trajectory were measured.

The results are shown in figures 2 and 3 and tabulated in Table IV. So far as field uniformity at the magnet center was concerned it was found that in the case of the inner coil, the field uniformity was better than 1% upto a distance of 1.5" both ways from the center and better than 1.5% upto a distance of 2". In the case of the outer coil, the field uniformity was better than 2% upto a distance of 1.5" from the center. With respect to field uniformity, the outer coil performance was slightly inferior compared to the inner coil, probably because of the higher ratio of diameter to length for the outer coil. However the overall performance of the outer coil, as measured by the variation of $\int B.dl$ over the 2" aperture at the center, was slightly better than the inner coil. The field integral is the most important parameter, hence the outer magnet is lightly better than the inner one. In this case the "end effect" better cancels the "3-D effect " on the internal field.

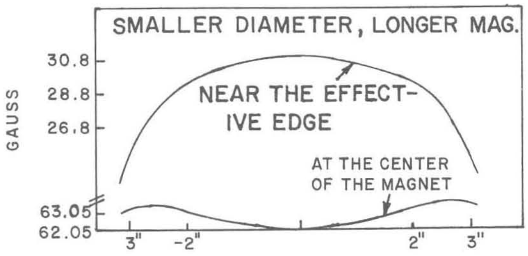

Fig.2: Magnetic field distribution in the median plane.

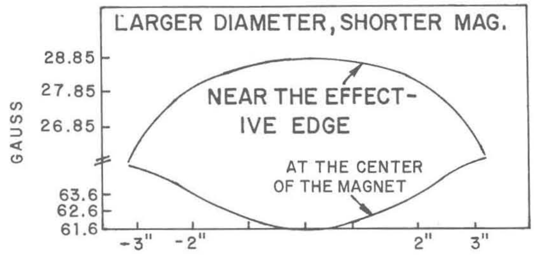

Fig.3: Magnetic field distribution in the median Plane.

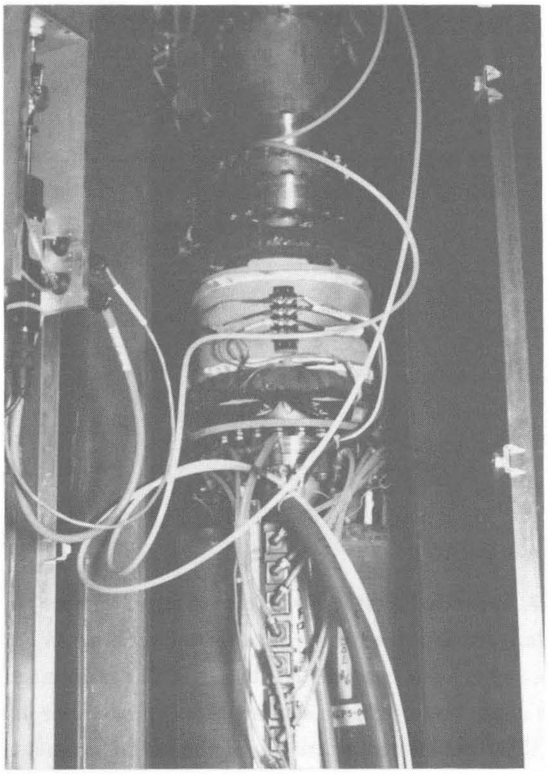

Fig.4 : The X-Y steering magnets installed in the K800 ECR beamline.

REFERENCES

1. M.F. Williams, A.F. Zeller and J.A. Nolen Annual Report Cyclotron Lab (1985) p. 172.

2. AECL-9262 Progress Report of the Atomic Energy Canada limited, (1986) January-June 30, Section 3-20.

3. R. Perin Proceedings of the Workshop on CEBAF spectrometer magnet design April (1986) CEBAF Virginia Appendix.

Table III

	Length	ϕ_1	ϕ_2	ϕ_3	r_1	r_2	NI	N	I	R
Inner Coil	9"	43.2°	52.1°	67.3°	4.0"	4.25"	1000	200	5A	3.5Ω
Outer Coil	6.5"	43.2°	52.1°	67.3°	4.25"	4.50"	1200	200	6A	3.8Ω

Table IV

		axis	2" off axis		% variation	Central B (Gauss) @ 5 amps
Inner	ΣBiLi (Gauss Inch)	2038.8	1998.7		1.97	61.6
Coil	L effective (Inch)	9.96	9.61			
			right side	left side		@ 6 amps
Outer	ΣBiLi (Gauss Inch)	1648.95	1644.9	1632.95	0.61	62.05
Coil	L effective (Inch)	8.11	7.84	7.83		