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ISABELLE QUADRUPOLES*

W.B. Sampson, K.E. Robins, S. Kiss, P.F. Dahl and A.D. McInturff
Brookhaven National Laboratory
Upton, New York 11973

SUMMARY

Each of the regular lattice quadrupoles for ISABELLE has three types of superconducting windings. The main windings are similar in design to the dipole coils and produce the principal focusing component. A set of quadrupole coils of much smaller radial thickness are situated just inside the main winding and provide a means for gradient trimming. A third set of windings is incorporated in the bore tube and consist of discrete multipoles which are used to control the "working line" of the storage ring. Construction details and performance data for the first full-scale model magnet are given in this report.

INTRODUCTION

In order to minimize the problem of synchronizing the dipole and quadrupole fields, all the magnets in the normal cells of ISABELLE[1] are connected in series. Since the saturation characteristics of the two types of coils are not precisely the same, a gradient adjusting coil is provided to maintain the tune at high fields. The degree of current control required in the power supply for this trim coil is much less than that which would be needed if the quadrupoles and dipoles were powered separately. Both the equilibrium orbit correcting dipoles and the coils required to avoid high order resonances are also included in the quadrupole assembly.

MAGNET DESIGN

A) Main Coils - The main windings of the quadrupole are of the cos 2θ type, fabricated from a wide flat braided conductor which has been described in detail elsewhere.[2] Each quadrant is formed separately using the technique developed for the dipoles and in the same molding fixture. All dimensions of the two types of coils are identical so that the four quadrants can be assembled and banded with the dipole tooling. After grinding to size the magnet is inserted into a cylindrical iron core which is similar to that used with the dipole. The turns distribution was calculated with the program MAGFLD to minimize the harmonic content at low fields.

B) Gradient Trim Coils - A second set of four coils made from a narrow braid approximately one-sixth as wide as that used in the main windings form the gradient trim coils. They are mounted on the bore tube on fiberglass epoxy bands and also banded externally to provide a support for the main winding. The amount of gradient variation provided in this design is plus or minus ten percent, considerably more than that required to compensate the difference in saturation characteristic of the dipoles and quadrupoles.

C) Multipole Windings - A number of discrete multipole windings are built into the bore tube. These include horizontal and vertical closed orbit correction dipoles and sextupoles and higher order windings for control of the "working line" during acceleration. A duodecapole (6θ) winding is provided to compensate for the twelve pole term introduced by iron saturation. Each winding is made from the same conductor, a seven strand cable of individually insulated multifilamentary NbTi composite. The strands are connected end-to-end after winding to give the equivalent of seven turns for each turn of cable. Slots in the fiberglass cladding on the stainless steel bore tube hold the winding which is interleaved, forming two radial layers of cable. Table I summarizes the multipole windings and their magnetic constants.

Table I.

Multipole Coil		Number of Turns/Pole	Magnet Constant
Dipole	(1θ)	126	21.5 G/A
Sextupole	(3θ)	133	1.8 G/cm^2 A
Octupole	(4θ)	7	2.5×10^{-2} G/cm^3 A
Decapole	(5θ)	7	6.2×10^{-3} G/cm^4 A
Duodecapole	(6θ)	7	1.4×10^{-3} G/cm^5 A

The general arrangement of the various types of windings in the magnet are shown in Fig. 1 and the rather complex end configuration is illustrated in Fig. 2. The parameters of the coils are given in Table II.

The quadrupoles are cooled by high pressure helium gas which passes axially down the magnet. Slots are arranged in the pole pieces of the main coil and gradient trim windings so that the gas must come in contact with both surfaces of these two windings and the upper surface of the multipole coils.

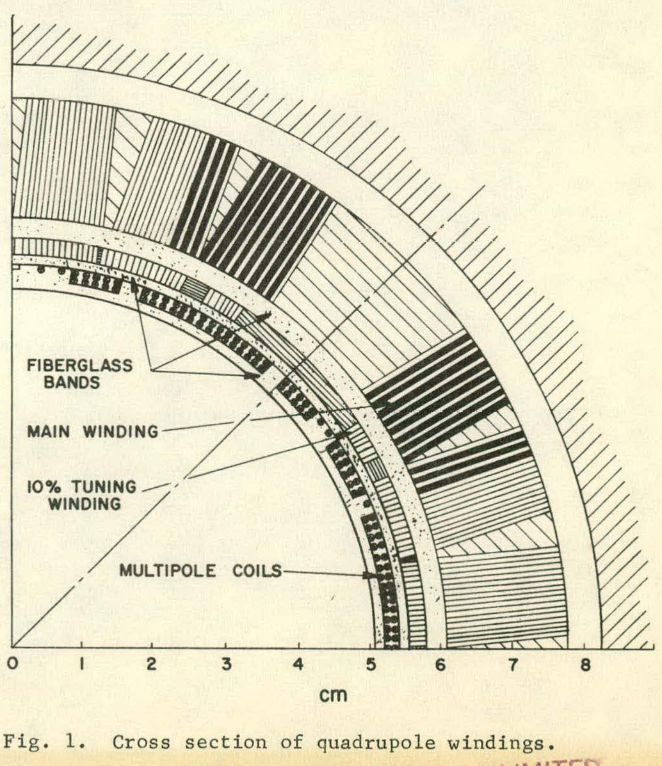

Fig. 1. Cross section of quadrupole windings.

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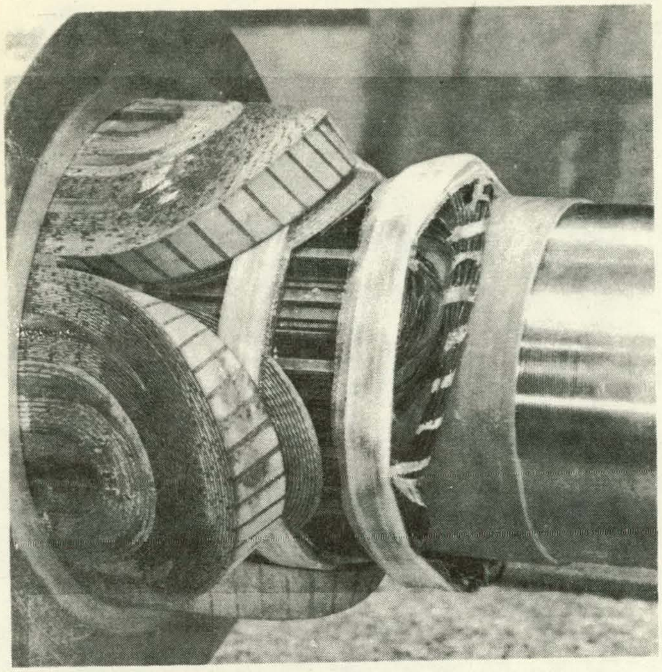

Fig. 2. End configuration of quadrupole coils.

Table II. Quadrupole Coil Parameters

Overall length of main coils	150 cm
Magnetic length	146 cm
Inner diameter of main coils	12 cm
Nominal operating current	3400 A
Nominal gradient	5.27 kG/cm
Inner diameter of gradient trim coils	11.2 cm
Inner diameter of multipole coils	10.5 cm
Multipole coil current rating	45 A

MAGNET PERFORMANCE

The main windings of the first quadrupole have been tested in the pool boiling mode.[2] The training observed was similar to that experienced with the dipoles and the design gradient was exceeded on the first quench. The maximum gradient achieved was 7.1 kG/cm, some 35% higher than the nominal design value. The effect of iron saturation on the gradient is shown in Fig. 3. At 3400 A the saturation effect in the dipole is approximately twice as great as for the quadrupole so that a gradient reduction of about 1.5% is required. Some of the magnetic measurements are given in Table III. The coefficients quoted are for the central or two dimensional region and the bracketed factors are the integrated field expressed as a fraction of the central region. Thus (1.0) implies that there is no end effect while a factor less than one implies a cancellation of the central field harmonics by the end fields and a factor greater than one on enhancement of the field. The large ratio for the 12 pole component at 4000 A is due to the fact that the central field harmonic is passing through zero near this current.

In a quadrupole the 12 pole term is the first allowed harmonic and is analogous to the sextupole term in a dipole. In Fig. 4 this harmonic is shown as a function of current and its behavior is very similar to that of the sextupole term in the dipoles.[2] The harmonics in Table III are somewhat larger than those expected for production quadrupoles, since the coils were molded using modified dipole tooling rather than precisely machine parts.

The quadrupole with all auxiliary winding is currently being installed in the half-cell test assembly and more complete results should be available in the near future.

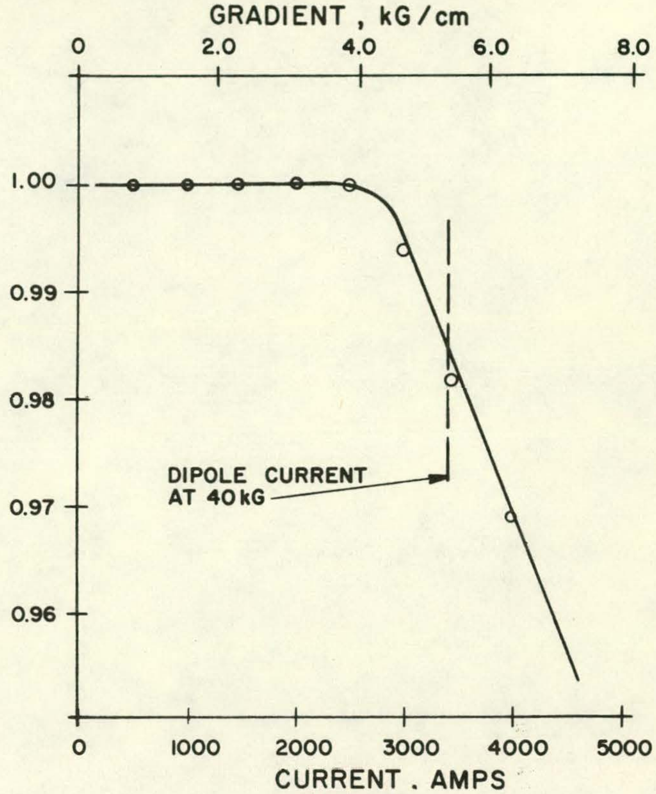

Fig. 3. Iron saturation effect in the quadrupole.

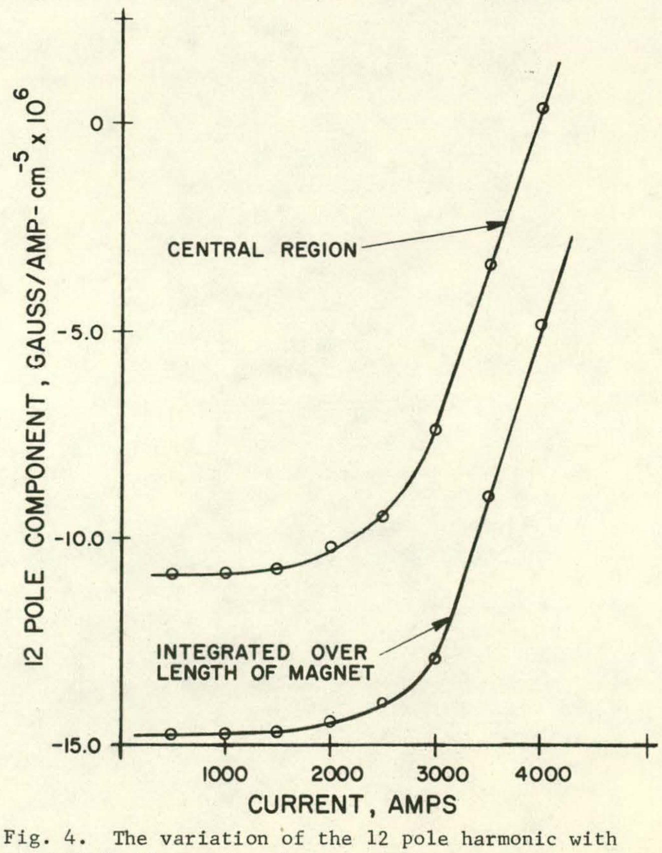

Fig. 4. The variation of the 12 pole harmonic with current in the quadrupole.

Table III. Magnetic Measurements

Current (A)	2θ (G/cm A)	3θ (G/cm^2 A)	4θ (G/cm^3 A)	5θ (G/cm^4 A)	6θ (G/cm^5 A)	10θ (G/cm^9 A)
1000	1.59 (1.0)	1.4×10^{-4} (2.5)	4.0×10^{-5} (0.99)	5.6×10^{-6} (0.88)	-1.11×10^{-5} (1.5)	3.5×10^{-9} (1.2)
2000	1.59 (1.0)	1.4×10^{-4} (2.6)	4.0×10^{-5} (0.99)	5.6×10^{-6} (0.88)	-1.04×10^{-5} (1.5)	3.4×10^{-9} (1.2)
3000	1.58 (1.0)	1.2×10^{-4} (2.9)	3.6×10^{-5} (0.91)	5.1×10^{-6} (0.94)	-0.74×10^{-5} (1.8)	3.6×10^{-9} (1.2)
4000	1.55 (1.0)	1.0×10^{-4} (3.7)	3.1×10^{-5} (0.93)	4.1×10^{-6} (0.99)	$+0.03 \times 10^{-5}$ (-18.4)	3.3×10^{-9} (1.3)

References

1. ISABELLE - A Proposal for Construction of a Proton-Proton Storage Accelerator Facility, BNL Formal Report 50519 (1970).
2. A.D. McInturff, W.B. Sampson, K.E. Robins, P.F. Dahl, R. Damm, D. Kassner, J. Kaugerts and C. Lasky, IEEE Trans. Magn. MAG-13, No. 1, 275 (1977).