CONFIGURATION OF THE PROPOSED DIAMOND SUPERCONDUCTING DIPOLE MAGNET

N. Marks, J.A. Clarke, CLRC, Daresbury Laboratory
and E. Baynham, R. Coombs, CLRC, Rutherford Appleton Laboratory.

Abstract

Whilst the majority of the dipole magnets in the proposed UK synchrotron source DIAMOND will be of conventional design, the option of including a small number of superconducting magnets, to provide hard radiation, is currently under consideration. The required field strength of 4.35 T is modest, but the large horizontal aperture and the short magnetic length place unusual demands on the design. To meet these, a number of possible configurations have been examined. These include a straight cylindrical arrangement, with cosine theta coil distribution and cold iron, and a rectangular coil configuration, with warm iron. The reported work is not a full design exercise, but rather a preliminary investigation to identify the most suitable configuration and for use in a more detailed study in the future.

1 SPECIFICATION OF THE S.C. DIPOLES

It is common for synchrotron sources to make use of superconducting technology for wavelength shifting wigglers; now a number of recent studies for new sources have also explored the use of superconducting dipoles as bending magnets at a small number of lattice positions. These magnets will produce s.r. beams with higher critical energy than the conventional bending magnets, with the minimum expenditure in r.f. power.

1.1 The DIAMOND requirements

A feasibility exercise for the proposed new U.K. source, DIAMOND, is nearing completion. This includes the possibility of replacing at least two of the 32 dipole benders by superconducting magnets. These would have the same deflection as the conventional dipoles but, with a much higher field, would be physically much shorter.

The problems associated with the design of the dipole are demonstrated by the parameters in Table 1. The field strength of 4.35T determines the very short magnetic length of 450mm. In the horizontal plane, space is required radially outside the standard 'beam stay clear' region, both to allow the full radiation fan from the s.c. magnet to emerge and also to house the absorber which receives the radiation from the up-stream dipole. This gives an asymmetrical horizontal aperture which is significantly greater than the vertical aperture and appreciable compared to the magnetic length.

Machine energy	3.0	GeV
Total number of dipoles	32	
Number of s.c. dipoles	at least 2	
Field in s.c. dipole	4.35	T
Magnetic length	450	mm
Field homogeneity	$\pm 2 \times 10^{-4}$	
Horizontal good field	± 20	mm
Vacuum vessel type	warm bore	
Vertical aperture	± 20	mm
Radial outer aperture	75	mm
Radial inner aperture	31	mm
Magnet sagitta	11	mm

Table 1: Parameters of the DIAMOND superconducting dipoles.

1.2 Possible Configurations

The standard superconducting dipole in high energy accelerators has a cylindrical coil geometry located close to a cold iron yoke; the cosine theta distribution of the conductors then provides a high quality dipole field. This arrangement is usually associated with magnets having lengths one to two orders of magnitudes greater than their aperture, so that end effects are negligible. Whilst the above geometry does not readily match this arrangement, the cylindrical configuration represents the 'classical' design, with well understood magnetic and mechanical behaviour. The cylindrical design was therefore regarded as a possible option and was investigated by the Rutherford-Appleton Laboratory team. At Daresbury Laboratory, an alternative solution, using rectangular coils in an approximate Helmholtz configuration, with warm iron, was investigated.

2 THE CYLINDRICAL MAGNET SOLUTION

2.1 Geometry

The layout developed to meet the geometric constraints used a fully symmetrical cylindrical design for the warm bore, cryostat, coil and the cold steel yoke; the arrangement therefore gave a vertical aperture in the beam tube that was significantly larger than the specified minimum value of ± 20mm. The geometric parameters of this magnet are given in Table 2.

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Warm bore radius	75	mm
Coil inner radius	95	mm
Iron cylinder inner radius	155	mm
Iron cylinder outer radius	355	mm
Cryostat outer radius	500	mm

Table 2: Cylindrical magnet geometric parameters

2.2 Adjustments to obtain an acceptable field integral.

The machine requirements given in section 1.1 dictate a winding aperture which is large compared to the good field region. Field quality at the beam will therefore be insensitive to high order harmonics produced by the coil. A simple 60° winding will eliminate sextupole errors in two dimensions and this was taken as the starting point for the design. The field quality of this arrangement was checked in two dimensions using the code, OPERA 2D; as expected, field which met the quality criteria was obtained. However, three dimensional non-linear modelling indicated that the end fields had a large negative sextupole component, which contributed strongly to the integrated field. These end effects were therefore balanced by introducing positive sextupole into the central section. It was found that by terminating the conductor at 45°, good integrated field was obtained through the magnet. Fig 1 shows the cross section through the magnet with this geometry, whilst Fig 2 presents an orthographic view of the complete magnet, showing the saddle arrangements at the ends of the coils.

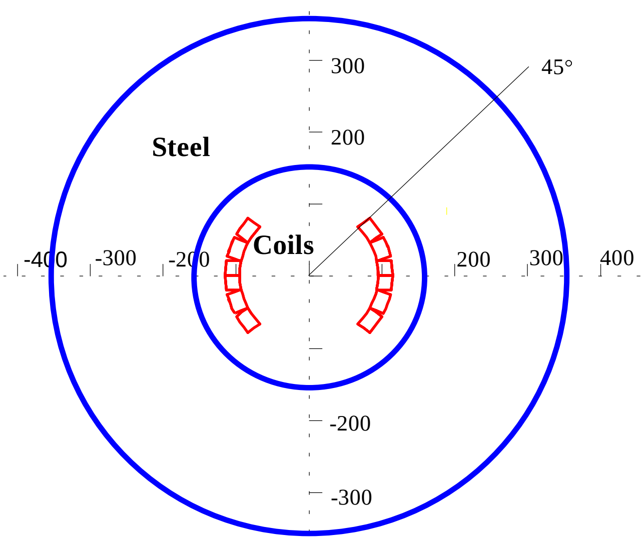

Fig: 1 Cross section through cylindrical design magnet showing coil and iron radial distribution.

The resulting field quality is presented in Fig 3 as a plot of integrated field through the magnet as a function of horizontal position. It can be seen that the integrated field is close to specification, with an error of +0.06% at 20mm. Additional optimisation to the coil configuration is expected to result in further improvements.

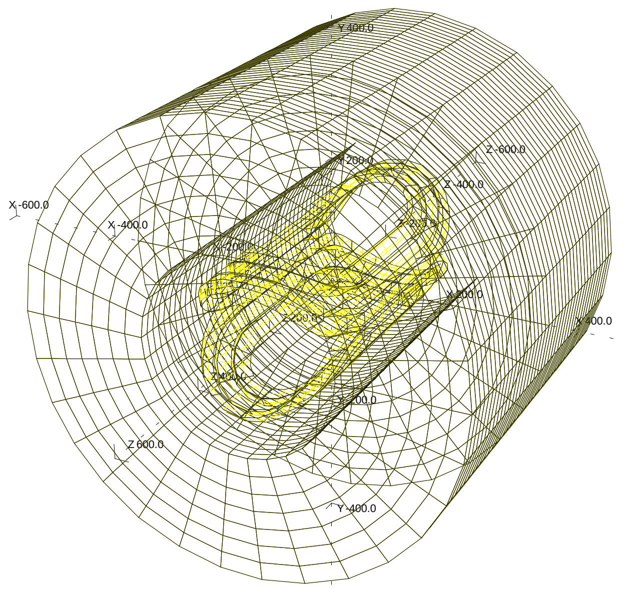

Fig: 2 Orthographic projection showing cylindrical magnet coil and iron geometry.

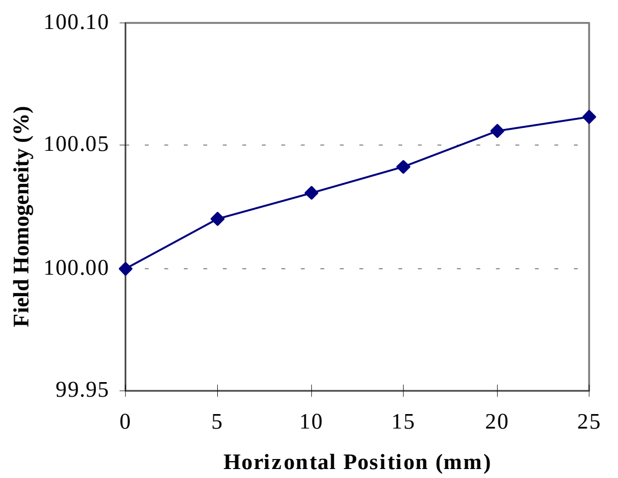

Fig: 3 Homogeneity of integrated field through the cylindrical magnet design as a function of horizontal position.

3 THE HELMHOLTZ COIL SOLUTION

This configuration is based on the ‘classical’ Helmholtz coil, with steel added to provide a flux return path. The central warm bore is of rectangular or elliptical cross section, with the two quasi-rectangular coils located in the cryostat and supported above and below the beam. The outer face of the cryostat is cylindrical and is surrounded by a substantial warm iron cylindrical yoke, to enhance the central field and minimise leakage.

3.1 Optimisation of coil geometry

It is known that, in the absence of iron, the 'classical' Helmholtz configuration gives good quality field on axis. However, the steel yoke and the curved corners at the coil ends distort the field and adjustments to the coil geometry are required to regain this quality. The arrangement shown in Fig 4 was used to model the magnetic behaviour in three dimensions, using the code OPERA 3D, and the radial coil position was adjusted to improve the integrated field distribution through the magnet. Table 3 gives the dimensions of the basic magnet geometry together with the coil positions that provided a closest match to the specification.

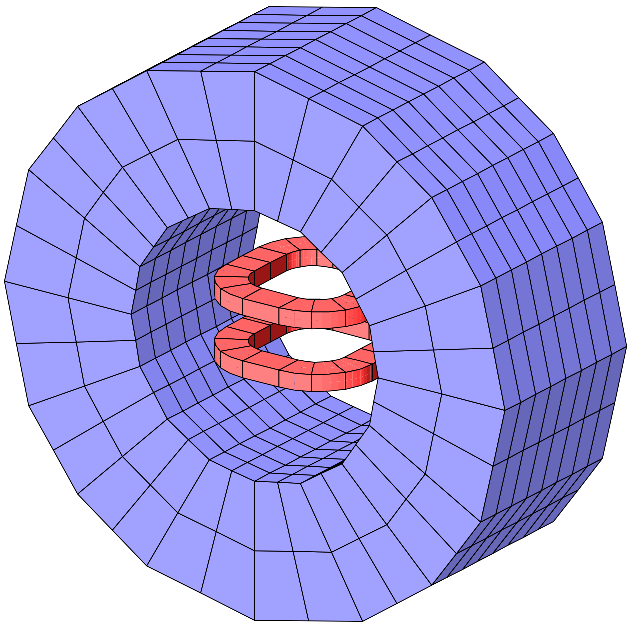

Fig: 4 Orthographic projection showing Helmholtz configuration magnet in three dimensions.

Warm bore width	+75, -31	mm
Warm bore height	± 20	mm
Coil centre horiz. position	170	mm
Coil centre vert. position	82	mm
Coil width	80	mm
Coil height	44	mm
Coil current density	250	A/mm^2
Cryostat outer radius	350	mm
Steel inner radius	355	mm
Steel outer radius	720	mm

Table 3: Helmholtz configuration magnet parameters.

The homogeneity of integrated field through the magnet is shown in Fig 5. This rises to 100.02%, before falling to 99.97% at the edge of the aperture. It was also found that with 4.35 T at the beam, the cylindrical yoke geometry resulted in a maximum flux density in the steel of the order of 1.6 T; the magnet was therefore very linear both in amplitude and field distribution.

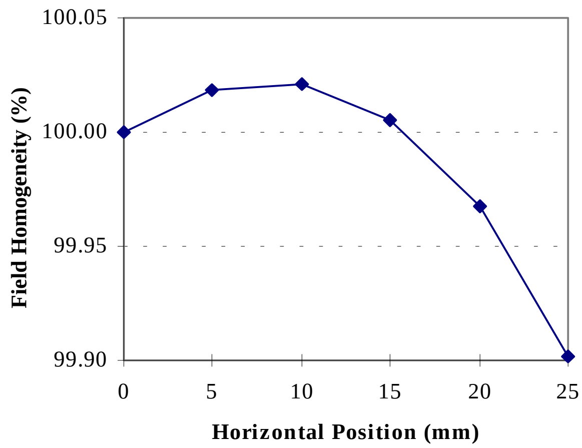

Fig: 5 Homogeneity of integrated field through the Helmholtz configuration magnet as a function of horizontal position.

4 CONCLUSION

The features of the two different arrangements are contrasted in Table 4. As the cylindrical arrangement is close to a well proven arrangement, there is confidence that a full design would result in an efficient, economic design. However, the alternative configuration, with its smaller cryostat, presents some advantages, whilst also presenting difficulties. It has therefore been decided to pursue the Helmholtz design further, to determine whether this will result in a cheaper and more flexible design, whilst holding the classical solution in reserve.

Feature of mag	Cylindrical magnet	Helmholtz magnet
Warm bore	Circular, symmetrical	Rectangular or elliptical - asymmetrical if required
Cryostat outer radius	Large - 500 mm	Smaller - 350 mm
Shape in axial direction	Straight	Could be curved
Steel	Cold - close to coil	Warm- remote from coil
Cold mass	Large - includes steel	Small - excludes steel
Asymmetrical forces, coil/steel	Directly reacted	Reacted through cryostat walls.

Table 4: Design features of the alternative configurations.