DIPOLE AND QUADRUPOLE MAGNET DESIGNS FOR DIAMOND

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Abstract

As part of pre-design study investigations for the proposed synchrotron source DIAMOND, suitable magnetic and engineering configurations for the storage ring conventional dipoles and quadrupoles have been examined. The paper presents details of the current specifications for these magnets and possible designs that meet these requirements.

1 INTRODUCTION

Work is proceeding at the Daresbury Laboratory on a possible future UK synchrotron radiation source, DIAMOND [1]. This is currently specified as a third generation, 3 GeV storage ring light source, with full energy injection from a booster synchrotron. It is envisaged that the storage ring lattice may include super-conducting as well as conventional dipoles, functioning as the main lattice bending magnets. Whilst a full energy injector is being considered, the possibility of lower energy injection is not excluded at this stage; hence, the dipole design is required to provide adequate field quality between 1 and 3 GeV. The lattice also requires twelve different families of quadrupoles to provide the required control of the beta values in the achromats and at the insertion devices.

Work, resulting from a collaboration between the CLRC's two laboratories, on the design of the conventional dipole and the various quadrupoles is presented. In all cases, the magnetic field distributions shown have been predicted using the Vector Fields code OPERA 2D [2].

2 CONVENTIONAL DIPOLES

The conventional dipoles have the following specification:

number of dipoles (inc. s.c. magnets)	32 ;
minimum possible injection field	0.46 T ;
maximum field	1.4 T ;
required field homogeneity	$\pm 2 \times 10^{-4}$;
horizontal good field aperture	± 20 mm ;
magnet half gap at orbit	25 mm.

After a number of iterations, a pole geometry that substantially meets the required field quality was generated. A cross section through the pole is shown in Fig 1.

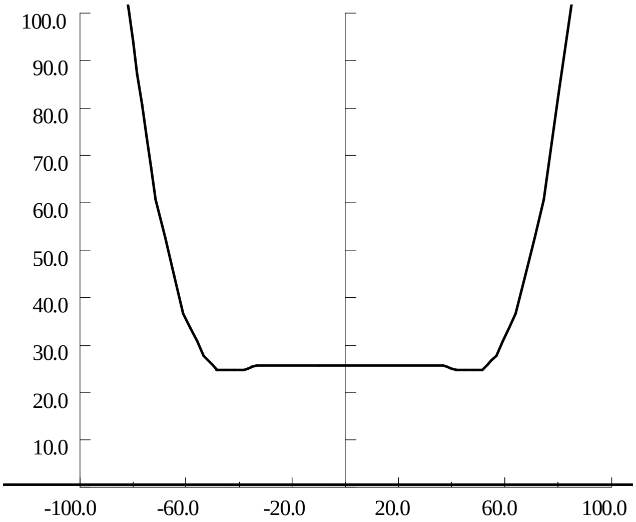

Fig 1: Pole geometry used for modelling the conventional dipole (dimensions in mm).

This pole geometry has the following parameters:

total pole width at root	180 mm ;
total pole width at shim	110 mm;
total shim width	20 mm;
shim height	0.9 mm.

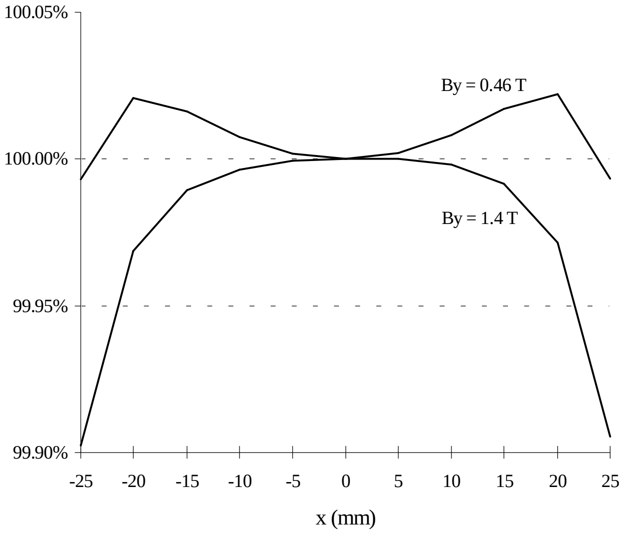

Fig 2: Homogeneity (%) of vertical field in the dipole as a function of horizontal position x.

The field quality predicted by OPERA 2D with non-linear steel (Magnetil BC) at both minimum and maximum fields is shown in Fig 2. It can be seen that the magnet meets the good field specification out to x = 18 mm at By = 1.4 T and exceeds the specification at the minimum field level.

3 QUADRUPOLE MAGNETS

The twelve quadrupole families have differing maximum strengths and, because of the variation of beam size through the lattice, differing aperture requirements. The relevant data is summarised in Table 1.

Table 1 Parameters for the twelve families of quadrupole magnet:

Fam.	**Max. grad.** **T/m**	**No/ fam.**	**Hor. half app.** **mm**	**l** **m**	**R** **mm**	**Cross Sec.**
Q 1	8.0	16	20	0.4	30	A
Q 2	20.0	16	20	0.6	30	B
Q 3	17.0	16	20	0.4	30	B
Q 4	8.0	12	20	0.4	30	A
Q 5	20.0	12	20	0.6	30	B
Q 6	17.0	12	20	0.4	30	B
Q 7	11.0	32	40	0.4	40	C
Q 8	15.0	32	40	0.4	40	C
Q 9	8.0	4	25	0.4	30	A
Q 10	12.0	4	25	0.6	30	B
Q 11	15.0	4	25	0.6	30	B
Q 12	8.0	4	25	0.4	30	A

Good gradient is currently defined as:

$$\Delta g / g(0) \leq 0.05\%.$$

In addition to giving the maximum required quadrupole gradient, the number of magnets per family, the required good gradient half aperture and the magnetic length, the sixth column of the Table also gives the minimum possible inscribed radii, determined from preliminary estimates of vacuum vessel dimensions.

A requirement to maintain a minimum clearance for emerging beam-lines in the regions of the pole and coil corners applies an additional constraint:

minimum allowed vertical pole and coil clearance = ± 10 mm.

The use of a different cross section design for each family would be highly uneconomic and therefore it is proposed to use only three quadrupole cross sections to accommodate all twelve families, there being different magnet lengths needed in some cases; the last column in Table 1 gives the cross section that is proposed for each family. Work on each of these cross sections is presented below.

3.1 Cross section A.

Cross section A is a low gradient magnet with a conservative good gradient aperture of 20 mm; little difficulty was encountered during the design work. Using a hyperbolic pole with a linear tangential shim commencing at:

x = 32.5 mm y = 13.85 mm

and terminating at:

x = 41.53 mm y = 10.00 mm

good quality gradient was obtained across the specified aperture. The gradient homogeneity is shown in Fig 3.

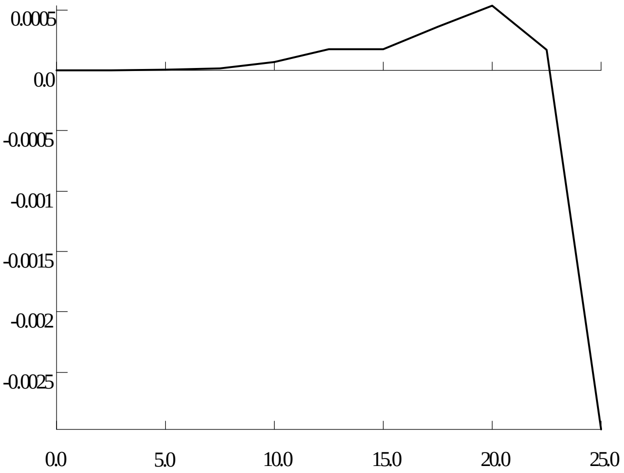

Fig 3: Fractional variation in gradient with horizontal position x (mm) on the y = 0 axis in the cross section A quadrupoles at a gradient of 16 T/m.

3.2 Cross section B.

This cross section has higher maximum gradient of 20 T/m and, in the case of families 10 and 11, a larger good gradient aperture of 25 mm. Difficulties encountered during the design included high flux densities at the pole root, which led to non-linear behaviour, and problems in obtaining the required gradient aperture without infringing the minimum specified pole clearance of 10 mm. A geometry that overcomes these difficulties is shown in Fig 4, the diagram showing one eighth of the total quadrupole.

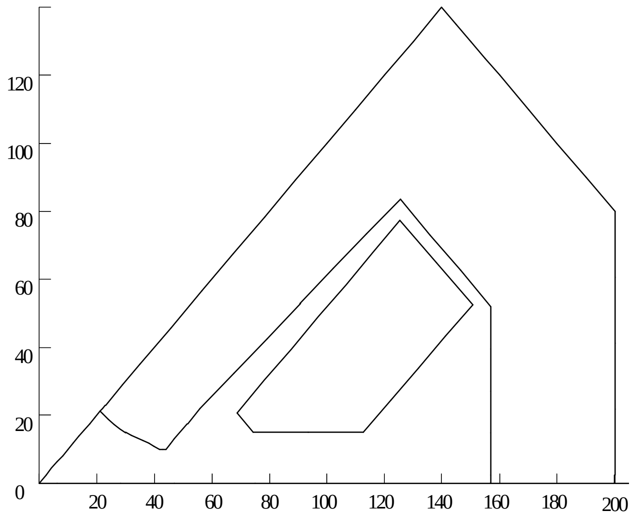

Fig 4: One eighth pole geometry for the quadrupole cross section B (dimensions in mm).

The hyperbolic pole is terminated by a linear shim commencing at:

x = 38.000 mm y = 11.842 mm;

and terminating at:

x = 41.800 mm y = 10.000 mm;

followed by a horizontal section, terminating at:

x = 44.000 mm y = 10.000 mm.

This horizontal section of the pole was found to be effective in extending the good gradient region, without infringing the region below y = 10mm. Additionally, the pole is thickened at the root, overcoming the problem of non-linearities. The predicted gradient quality for this geometry at g = 20 T/m, with non-linear, Magnetil BC steel, is shown in Fig 5.

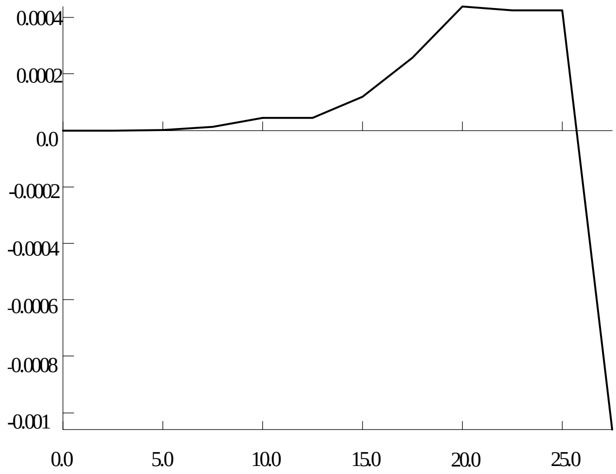

Fig 5: Fractional variation in gradient with horizontal position x (mm) on the y = 0 axis in the cross section B quadrupoles at a gradient of 20 T/m.

3.3 Cross section C.

It was found to be possible to obtain the full 40mm good gradient aperture with the 40mm inscribed radius by using a linear shim commencing at:

x = 53.000 mm y = 15.094 mm

and terminating with the pole corner at:

x = 66.000 mm y = 11.392 mm.

The predicted gradient quality at 15 T/m with non-linear steel for this geometry is shown in Fig 6.

It can be seen from the figure that the inscribed radius of 40 mm helps to establish a larger good gradient region without infringing the 10 mm clearance.

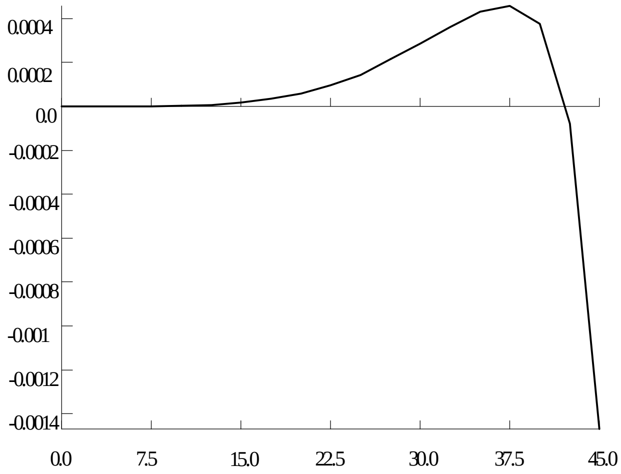

Fig 6: Fractional variation in gradient with horizontal position x (mm) on the y = 0 axis in the cross section C quadrupoles at a gradient of 15 T/m.

4 CONCLUSION

The work reported represents an initial examination of the quadrupole arrangements for DIAMOND. This information can now be used for more detailed examinations of the engineering layout of the lattice and for the assessment of field and gradient quality using particle tracking programmes. Further refinements and adjustments are then expected.

REFERENCES

[1] ‘Further Design Progress on DIAMOND, the Proposed New UK National Light Source’, M.W. Poole and V.P. Suller, these Proceedings.

[2] Produced by Vector Fields Ltd., 24 Bankside, Kidlington, Oxford OX5 1JE, UK