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MAGNET DESIGN FOR THE DIAMOND DDBA LATTICE UPGRADE

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Abstract

The DDBA lattice upgrade for Diamond presents challenging requirements on the magnet system in order to satisfy the tight constraints on the beam optics. Advanced, combined function dipole gradient and high gradient quadrupoles are needed. We present the tolerance specification, the design solutions and the measurement and alignment strategies.

INTRODUCTION

In the framework of the lattice studies for a possible upgrade of the Diamond storage ring [1] we have recently investigated a lattice based on the Double Double Bend Achromat (DDBA) cell [2]. This lattice gives the opportunity of creating one additional short straight section in the middle of the arc, which would align with the existing bending magnet ports in the Diamond shield wall. The present status of the project is described in a companion paper [3]. More details on the engineering design and integration are reported in [4-5].

The tight control of the optics in the DDBA cell demands advanced magnet design comprising four gradient dipoles with 0.8T and 14 T/m, providing the necessary vertical focussing. The DDBA cell has also ten horizontal focussing quadrupoles designed to generate 70 T/m. Such quadrupoles require a small bore radius of 15 mm with noticeable consequences on the engineering and vacuum design of the whole cell. The DDBA cell will also comprise ten sextupoles and two dedicated orbit correctors.

MAGNET DESIGNS

The magnet design has been driven by a number of constraints mostly related to the limited longitudinal space available within the existing cell, requiring very tight control of the physical length of the magnets. As the cell design and the engineering integration improved, significant effort has been spent to standardise the design of all magnets. In the final design only the dipole comes in more than a single variant while all quadrupoles have the same length (10 quadrupoles, 25 cm long) and all sextupoles have the same length (10 sextupoles, 17.5 cm long) despite belonging to different accelerator physics families. The extracted photon beam line also has to pass through many of the magnets and limits the size of the coil packs in the multipoles. The parameters for each magnet are reported in Table 1. The magnets are also designed such that they use the same specification of power supplies as the existing magnets.

Table 1: Magnet Specifications

Magnet	Parameter	Value
Dipole	Effective Length	0.67 & 0.967 m
	Physical length	0.65 & 0.95 m
	Nominal field	0.8 T
	Gradient	14.385 Tm^{-1}
Quadrupole	Effective Length	0.25 m
	Physical Length	0.32 m
	Gradient	70 Tm^{-1}
	Bore	30 mm (diameter)
Sextupole	Effective Length	0.175 m
	Physical Length	0.232 m
	Gradient	2000 Tm^{-2}
	Bore	30 mm (diameter)
	Corrector strengths	
	Horizontal	8 mTm
	Vertical	8 mTm
	Skew Quadrupole	0.1 T
Corrector	Physical Length	0.102 m
	Aperture	70 x 70mm
	Strength	
	Horizontal	8 mTm
	Vertical	8 mTm

Dipole

The two gradient dipole designs have the same dipole field and quadrupole gradient but different effective lengths, so they use a common profile. The magnets are C-type made in solid iron. The tight space constraints have led to a design using nose overhangs on the poles. This design forces the use of solid steel rather than laminations, to ensure a good flux distribution in the noses. Initially a design mounting the coils on the backleg was evaluated and while this could be shorter it was decided that the split in the backleg necessary to mount the coils introduced an unacceptable reduction in assembly accuracy. The coils will be therefore mounted in the pole.

The design of the pole profile has been optimised in 3D in order to provide the required field profile over ±10 mm inside the aperture. The main profile is a truncated hyperbola and the high field edge of the dipole is terminated with a Rogowski roll off to limit pole tip saturation. Chamfers at both ends allow an effective control of the higher order multipoles by optimising angle and rotation of the chamfer. The magnetic field contour lines are reported in Figure 1.

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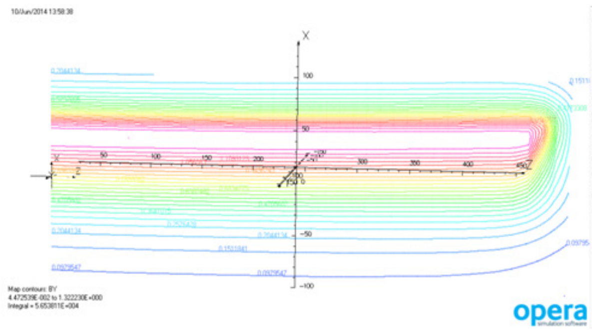

Figure 1: field B_y cut in the midplane of the dipole gap.

The whole pole can be dismounted in order to install the coils and then reassembled. The mechanical tolerances on the pole profile are challenging and the design has total budget of ±25 µm. The errors in the field quality appear to be dominated by the variation in the quadrupole component and to a lesser extent by the sextupole and octupole. The magnet current will be set for the correct quadrupole and the transverse position will be adjusted to set the correct dipole. The 3D view of the gradient dipole is shown in Figure 2.

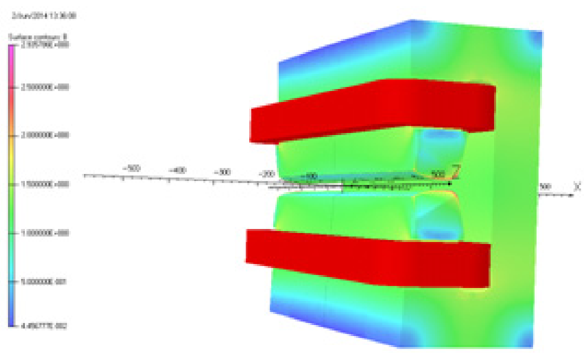
Figure 2: OPERA 3D view of the dipole.

These magnets are substituting for existing magnets in the main dipole circuit of the storage ring and it has been decided that they should be primarily powered from the existing main dipole power supply. However they have very different characteristics from the existing magnets and would not produce the correct fields at the setting required by the other dipoles, therefore there is also a trim coil on each magnet. The trim winding is a smaller conductor run at much lower current. Advantage has been taken of this to utilise the smaller bend radius and nest the two coils inside each other.

Quadrupole

The quadrupole magnets in DDBA are required to deliver a gradient up to 70 Tm^{-1}. The design chosen has a bore radius of 15 mm. The overall dimension of the quadrupole is 510 x 510 x 320 mm^3 and fits in a limited available space in transverse and beam directions.

The pole profile follows an approximately hyperbolic shape and the systematic multipoles are within the Accelerator Physics specifications. The pole base was made wide to minimise saturation and consequent reduction in the field quality. This restricts the space available for the coils. The width of the pole base was optimised to get reasonably low current density in the coils. With the present design 68 Tm^{-1} are reached with a current density of 3.85 Amm^{-2}. The coil design also provides clearance of 17 mm between the adjacent coils to provide space for the outgoing photon beam pipe. The deviation from the standard hyperbolic profile minimises the systematic 12 pole and 20 pole components. Entry and exit tapers were also optimised to minimise the systematic multipoles. The 3D view of the quadrupole is shown in Figure 3.

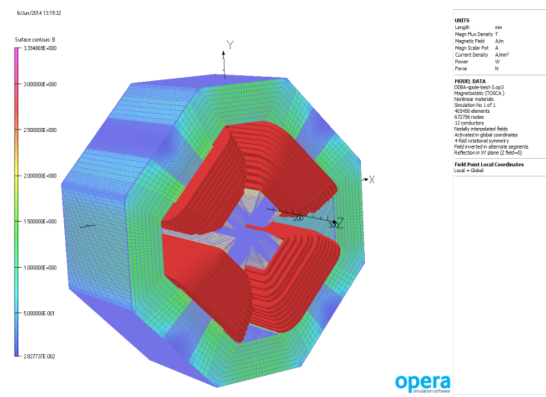

Figure 3: OPERA 3D view of the quadrupole.

The yoke will be made of solid iron. As for the dipole, tuning of systematic harmonics can be done by adjusting the pole tip profile and to some extent the chamfer at the quadrupole ends. Unwanted non-systematic multipole will be corrected by shims in the return yoke.

Sextupole

The sextupole is conventional and does not reach any significant levels of saturation. The pole profile is circular truncated with assembly chamfers. There are no end chamfers to fine tune the systematic multipoles. The design replicates the one used in Diamond. Horizontal, vertical correctors and skew quadrupole windings are mounted on the yoke. These will be included on all sextupoles although only a selection will be used. The 3D view of the quadrupole is shown in Figure 4.

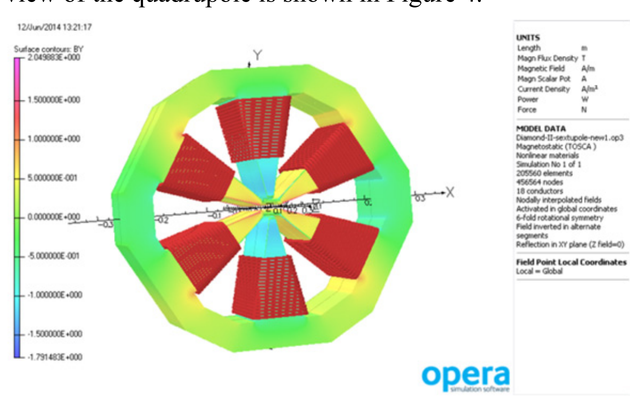

Figure 4: 3D OPERA vie of the sextupoles.

Correctors on six sextupoles out of ten in the DDBA cells will be part of the fast orbit feedback system. Therefore, in order to achieve the required response up to

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100 Hz, the yokes will be made from 0.5 mm thick laminations. The overall dimension of the sextupole is 473 x 460 x 232 mm^3.

Dedicated Corrector

Although correctors are embedded in the sextupoles, it was found that their location in the cell was not effective to control the orbit in the mid-straight section of the DDBA. Therefore an additional pair of correctors was required. Due to the very limited space available we investigated a solution with an integrated horizontal and vertical corrector built on the same rectangular iron yoke with just 102 mm length despite a pole gap of 70 mm. Such wide aperture is required to guarantee a good field quality for both corrector fields. The correctors are closely packed between a dipole and a quadrupole. The magnet interference between these magnets was found to be limited and the change in the integrated gradient is estimated to be ~0.03T and in the integrated dipole ~0.002Tm. Other higher order multipoles generated by the interaction are negligible. These changes can be compensated for, by adjusting the excitation current.

TOLERANCE SPECIFICATIONS

The impact of the predicted systematic multipole components arising from the magnet design has been assessed. Extensive numerical simulations of the dynamic aperture and Touschek lifetime [5] also included random multipolar components, scaled from the existing magnet measurements. The values reported in Table 2 refer to the most concerning multipolar components for each magnet, normalised at a radius r = 10 mm. These were found to be acceptable. Some work has been undertaken to refer the harmonics specifications back to alignment and build tolerances of the individual magnets. The surface and alignment tolerances are summarised in Table 3.

Table 2: Field Tolerances (n =2 for sextupoles)

Magnet	Parameter	Value (T)
Dipole	b2	-3.97E-04
	b3	-4.66E-05
Quadrupole	b3	-2.52E-04
	b5	1.85E-05
	b9	1.29E-04
Sextupole	b4	-0.53e-4
	b8	-1.00e-4

MEASUREMENT AND ALIGNMENT STRATEGY

The dipoles will require field mapping by a Hall probe bench. Fiducials for final positioning of the dipole on to the girder will be referenced during this process. The position accuracy of the measurement needs to be at least 5µm, and on the field measurement 0.2mT. It is intended to use an ESRF stretched wire measurement bench [6] to measure the alignment and harmonic content of the multipole magnets. This system will initially be used in the factory for the characterisation of the magnets and then reused at Diamond. A dedicated short girder will be supplied with the system to the manufacturer to ensure that the means of mounting for the initial tests will be the same as for the final alignment. The detail process for transferring the alignment data from the measurement to the supports and fiducials is yet to be fully defined. This final alignment of the multipoles is to be undertaken using the same stretched wire system relocated onto the girder and with all multipole magnets installed. The towers to support the measuring apparatus will be located in the dipole positions and at each end of the girder, relocated to measure each set of multipoles. Final alignment in situ with surrounding magnets also in place should ensure that the alignment between adjacent multipoles is as good as possible and takes into account the effect of adjacent magnets. There will be some effect due to the dipoles not being in place but it is anticipated that the final alignment will be better than 30 µm on the girders. A pin and shim alignment system is being designed for all the magnets. This is required to give an adjustment range of ±1mm in all planes for the multipole magnets. The transverse adjustment range for the dipoles is increased to ±2mm and has to be adjustable in situ. This allows for a mismatch between the correct setting of nominal field and gradient to be compensated. The accuracy of this system is required to be 10 µm. Final detail design of this system is still in progress.

Table 3: Mechanical Tolerances

Magnet	Parameter	Value
Dipole	Pole surface gap	10 µm ±15 µm
Quadrupole	Pole Surface Pole spacing	20 µm ±15 µm
Sextupole	Pole Surface Pole spacing	20 µm ±15 µm
Corrector	Pole spacing	±500 µm

CONCLUSIONS

We have presented the magnet design for the DDBA upgrade of the Diamond storage ring. Despite the challenging requirements, no showstoppers have been identified. The magnet procurement is underway and delivery is foreseen within 17 months for one DDBA cell.

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