ANALYSIS AND COMPENSATION OF CROSSTALK EFFECTS FOR THE DIAMOND-II BENDING MAGNETS

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Abstract

The close proximity of the magnets on the Diamond-II girders leads to significant crosstalk effects. This is of particular concern for the dipole component of the bending magnets, as the truncation of the fringe fields reduces the integrated strength and distorts the closed orbit. Tuning of the field amplitude and accurate alignment of the magnets is required to recover the target bend angles. A similar effect is seen on the quadrupole fields, and adjustment of the nominal gradients is required to restore the design optics. In this paper we present an overview of the modelling methods and latest results from these studies.

INTRODUCTION

In the latest generation of electron storage rings, crosstalk between magnets can be significant and must be considered during the design, construction and commissioning phases [1–3]. Compact layouts mean that magnet spacing is frequently below 100 mm, and despite having relatively small bore radii, fringe fields can overlap with the adjacent yokes. This causes a reduction in the integrated strengths and introduces unwanted multipole components.

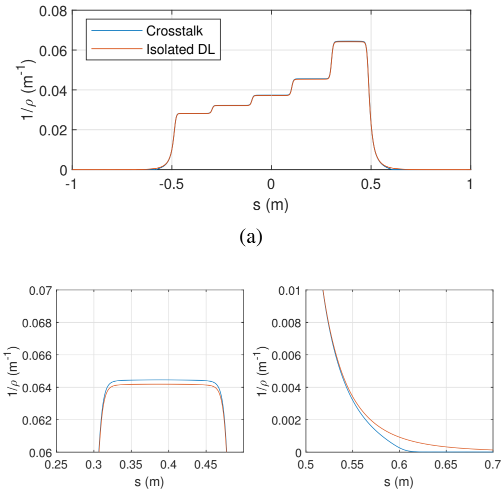
In the case of Diamond-II [4], the minimum distance between the hard-edge magnet models has been set to 75 mm. At this level, it is anticipated that crosstalk effects will need to be compensated by adjusting target field strengths and realigning the magnets to recover the design parameters. The storage ring contains three families of bending magnet; two types of permanent magnet (PM) longitudinal gradient bends (DL dipoles) and one type of electromagnet (EM) transverse gradient bend (DQ dipoles). Here we present crosstalk studies for these dipoles. Four combinations are considered, namely:

1) Q2L-DL-Q3L: type 1 DL dipoles on girders adjacent to long straights
2) Q2N-DL-Q3N: type 1 DL dipoles on girders adjacent to standard straights
3) Q4N-DL-S5X: type 2 DL dipoles in the centre of each girder
4) Q5N-DQ-Q6N: DQ dipoles adjacent to the mid-straights

OPERA FIELD MAPS

The first stage of the analysis is carried out in OPERA. For each magnet combination, a model is constructed consisting of a dipole in the centre and two quadrupoles (or quadrupole and sextupole) located on either side. All magnets are set to the nominal integrated field strengths. A particle is then tracked through the resulting field map, starting on the design trajectory at a point where the field strength is negligible. The dipole position and strength are then adjusted until the final particle coordinates match the target values, again at a point where the field has dropped to negligible levels. Once the real trajectory is known, the multipole components can be extracted along this path using spherical harmonics.

An example of the dipole component with and without crosstalk effects is shown in Fig. 1 for case 3). As can be seen, the main impact of the crosstalk is to reduce the magnetic length, which in turn reduces the bend angle for the reference particle. This can be compensated by increasing the field strengths of all modules by 0.55 %, 0.49 % and 0.43 % for cases 1-3 respectively, and shifting all type 1 DL dipoles by 0.5 mm longitudinally. For case 4), the DQ dipole needed to be shifted outboard by 80 µm. Table 1 summarises the impact of crosstalk on the dipole magnetic lengths, after the corrections have been applied.



(a)

(b) (c)

Figure 1: Comparison of dipole bend radius with and without crosstalk. (a): full magnet. (b): peak field. (c): falling edge.

Table 1: Impact of Crosstalk on Magnetic Lengths

Combination	Hard Edge	Without Crosstalk	With Crosstalk
Case 1)	1.153 m	1.157 m	1.150 m
Case 2)	1.153 m	1.155 m	1.150 m
Case 3)	1.116 m	1.114 m	1.110 m
Case 4)	0.870 m	0.870 m	0.867 m

The differences between the design and tracked trajectories are shown in Fig. 2 for case 3). Excluding crosstalk, the soft fringes of the DL dipole bend the beam trajectory

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earlier than the hard-edge magnet, shifting the trajectory inboard by a maximum of 28 µm. Once crosstalk effects and corrections are applied, this reduces to 4 µm.

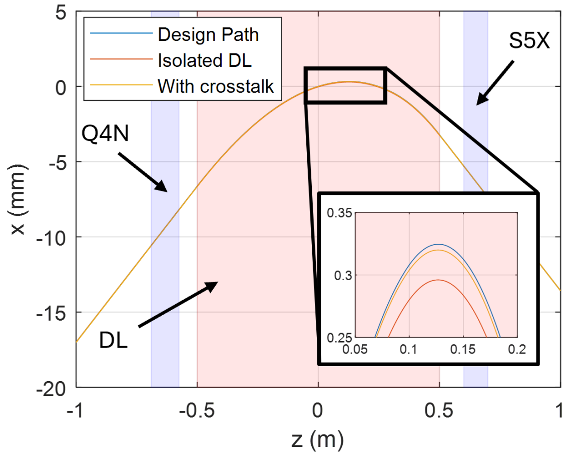

Figure 2: Comparison of tracked beam trajectory to the design path, with and without crosstalk effects.

MODELLING IN ACCELERATOR TOOLBOX

The next stage of the analysis is to incorporate the correct field profiles in the particle tracking code. For this, we use Accelerator Toolbox (AT) [5, 6]. The fields are added by replacing the hard-edge magnet models and intervening drift spaces with 1 mm long sector-bend elements and applying the correct s-dependent multipole values found from the OPERA model. Multipole components up to $n = 7$ are included.

As a first step, each crosstalk combination is studied in AT in isolation. The initial linear optics are extracted from the sliced model, after which the betatron tunes are corrected by adjusting the local quadrupole strengths. The results are summarised in Table 2. By applying the OPERA fields in this way, the changes required to compensate for both the crosstalk and the soft fringe-field effects are applied simultaneously.

Table 2: Comparison of Integrated Quadrupole Strengths for Hard-Edge and Crosstalk Models

Case	**Magnet**	**Hard-Edge (m^{-1})**	**With-Crosstalk (m^{-1})**	**Ratio**
Case 1)	Q2L	-0.485	-0.485	0.998
	Q3L	-0.391	-0.397	1.015
Case 2)	Q2N	-0.791	-0.788	0.996
	Q3N	-0.596	-0.602	1.011
Case 3)	Q4N	-0.612	-0.615	1.006
Case 4)	Q5N	2.144	2.136	0.996
	DQ	-2.414	-2.403	0.996
	Q6N	1.831	1.833	1.001

Having applied an initial tune correction for each magnet combination in isolation, the next step is to create a fully-sliced model of the ring including all the main dipole magnets. This is shown in Fig. 3. Sections of the ring replaced with the OPERA crosstalk fields are highlighted in red.

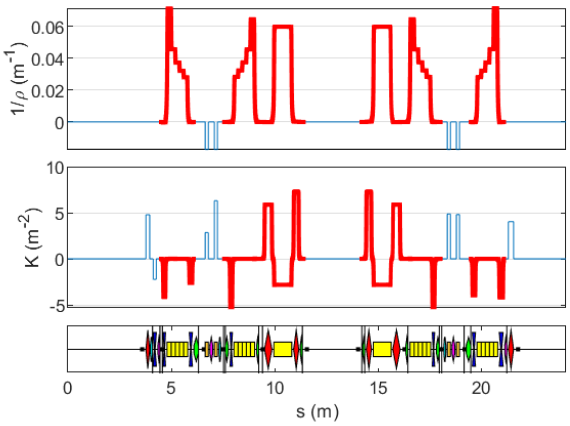

Figure 3: Bend radius and quadrupole strengths for sliced elements (red dots).

The initial tune corrections applied using the local quadrupoles are found to provide a good baseline level of optics control (see Fig. 4). Residual beta-beat is below 2% in both planes and the dispersion error peaks at -4.5 mm. A final tune correction is applied using the quadrupole magnets on long and standard straight sections (families Q0L, Q1L and Q1N), and chromaticity is then corrected using two families of chromatic sextupoles in the dispersion bumps (families S2A and S3A). A comparison of the storage ring parameters before and after final corrections with the design values is given in Table 3.

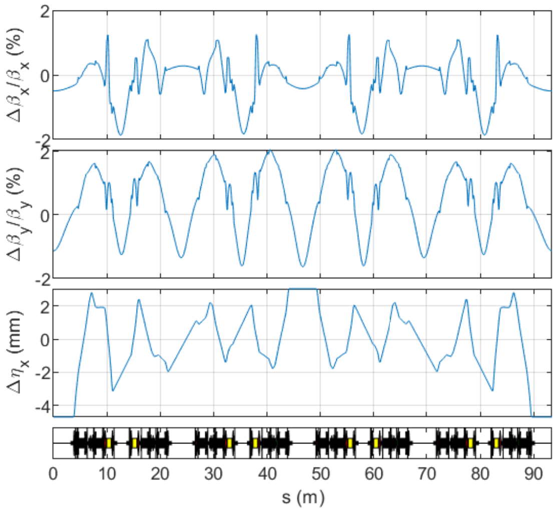

Figure 4: Residual optics errors after local gradient corrections to compensate for crosstalk and finite fringe fields.

The introduction of the systematic higher-order multipole components coming from the crosstalk and fringe fields is found to have a significant impact on the tuneshifts with amplitude, particularly above 4 mm in the horizontal plane and 1 mm in the vertical plane. This is shown in Fig. 5. Impact on the tuneshifts with energy is found to be small. The changes to the nonlinear lattice are found to have a direct impact on the size of the on-momentum dynamic aperture, as can be seen by comparing Figs. 6 and 7. However, the dynamic aperture remains larger than the anticipated physical acceptance once ID gaps and collimators are closed [4].

Table 3: Impact of Crosstalk on Ring Parameters

Param	**Hard Edge**	**With Crosstalk**	
		Before Correction	**After Correction**
Q_x	54.140	54.134	54.140
Q_y	20.240	20.253	20.240
ξ_x	2.56	3.48	2.56
ξ_y	2.60	3.05	2.60
ε_x	161.6 pm	163.9 pm	163.8 pm
σ_E	9.38×10^{-4}	9.38×10^{-4}	9.38×10^{-4}
α_c	1.03×10^{-4}	1.04×10^{-4}	1.04×10^{-4}

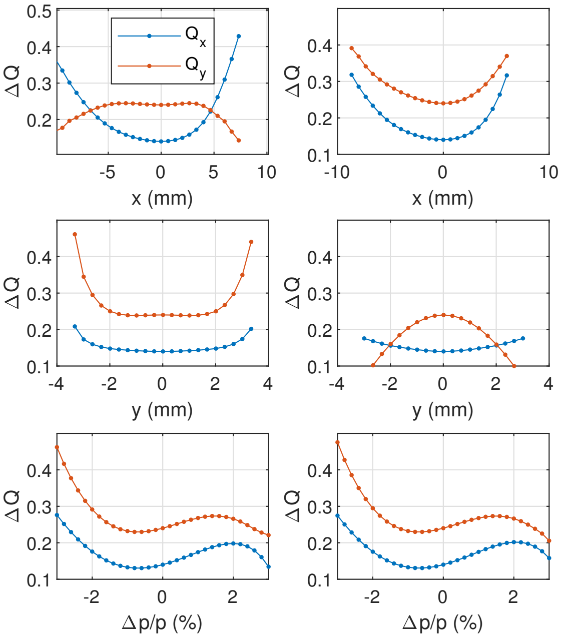

Figure 5: Comparison of tune-shifts with amplitude and energy. Left column: ideal hard-edge model. Right column: including crosstalk.

CONCLUSIONS AND FUTURE PLANS

The corrections in dipole alignment and field strengths identified in these studies have been included in the magnet and girder construction plans. Similarly, the updated target quadrupole strengths will be used for initial storage ring commissioning. Next steps are to conduct a similar analysis for the anti-bend magnets, after which the machine model can be updated to determine the final nonlinear performance. If necessary, this lattice can then be used to reoptimise the harmonic sextupole and octupole strengths to recover the dynamic aperture.

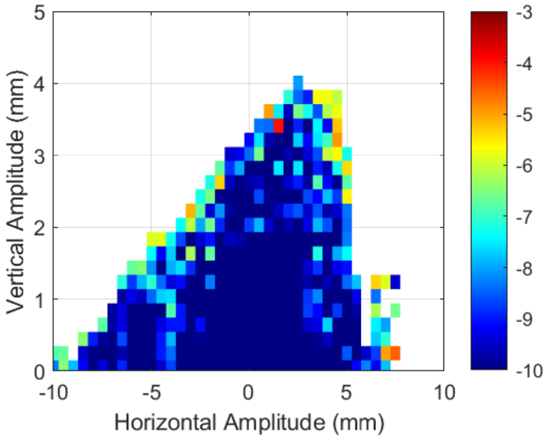

Figure 6: Dynamic Aperture for ideal hard-edge model.

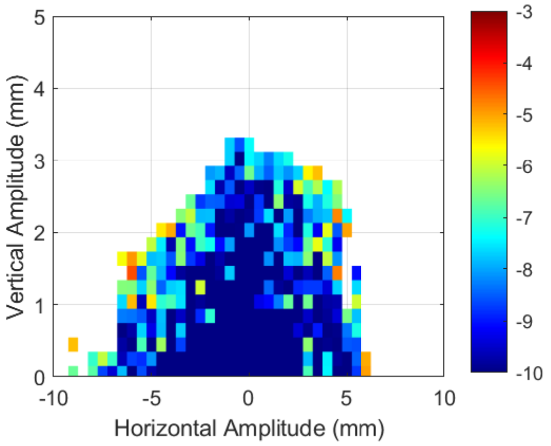

Figure 7: Dynamic aperture including crosstalk and field components up to $n = 7$ and after tune correction.

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