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A SINGLE DIPOLE SOURCE FOR BROAD-BAND SOFT PHOTON BEAMLINES IN DIAMOND-II

M. Apollonio*, MAX IV Laboratory, Lund University, Lund, Sweden
G. Cinque, H. Ghasem, I. P. S. Martin, A. N. Jury, R. Rambo
Diamond Light Source, Oxfordshire, UK

Abstract

Diamond-II is a project based at Diamond Light Source for an upgrade towards a Storage Ring characterized by a reduction of a factor 20 in its natural emittance and a doubling of the number of straight sections. At Diamond-II the majority of existing beamline capacity should be maintained, while enhancing their performance thanks to the increase in brightness at the source points. The substantial modification of the lattice imposes a likewise re-design of the broad-band sources, presently based on standard dipoles. In this paper we discuss a possible solution for the IR/THz beamline B22 operating within a photon energy range between 1 meV and 1 eV. This proposal, ideal for low critical energy and single source point sources, entails the insertion of a dipole in one of the newly created mid-cell straights of the machine, while reducing the bending power of the nearby gradient dipoles. After performing the linear matching of the lattice, reproducing a comparable phase advance in the modified cell, we studied the non-linear dynamics of the system. Comparison of the main observables (Dynamic Aperture, Injection Efficiency and Lifetime) with the baseline case is discussed.

INTRODUCTION

The Diamond-II lattice [1, 2] is based on a Modified Hybrid 6 Bend Achromat cell (M-H6BA), stemming from the original design of the EBS upgrade [3] of ESRF (H7BA), and creating a mid-straight that increases the density of IDs present in the machine. This geometric opportunity represents also a natural solution for the Diamond bending magnet sources (BM) and indeed the use of alternatives to dipoles, like three pole wigglers (3PW) has been the subject of initial investigations [1]. When re-hosting a BM source, few key points need to be considered:

- energy range,
- beamline acceptance angle and source size,
- effectiveness in extracting synchrotron radiation (SR),
- potential interference by other magnets.

In this paper we focus on the specific case of the infrared BM beamline at cell-22 (K22), for which initial studies illustrated the comparison between three possible solutions: (a) the gradient upstream dipole DQ, (b) a three-pole wiggler (3PW) placed in the mid-straight and (c) a single dipole in the mid-straight complemented with a modification of the upstream and downstream DQ elements, to close the electron trajectory. The 3PW (Fig. 1, blue line) appears to have the highest flux across the overall energy range of the beamline ([1 meV, 1 eV]) however it also bears a considerable effect of spectral and source interference, generated by the interplay between the series of poles of the device. A DQ dipole (black dashed line) might seem a straightforward choice, essentially replacing the existing BM (red dashed line), however, a considerable amount of SR would be not captured at the front end, mainly due to the large emission angle at such low energies. A detailed engineering design is currently being developed to quantify the limiting acceptance. An interesting alternative would be to use a single dipole placed in the mid-straight. This would give a flux comparable with the proposed 3PW, no extra sources, plus a smooth SR spectral emission free from interference.

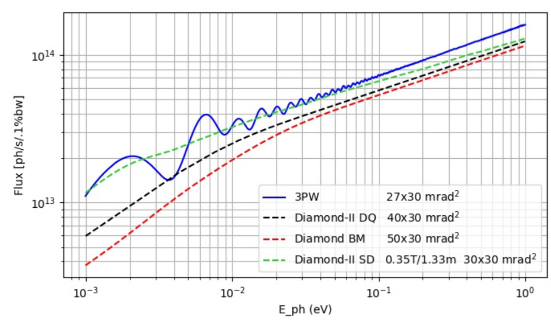

Figure 1: Preliminary study comparing the spectral flux of a 3PW (blue), the present BM at Diamond (red) a DQ element at Diamond-II (black) and for a single dipole (green). Achievable beamline acceptances are currently being clarified.

In order to realize such setting, the upstream and downstream DQ dipoles need their bending power to be reduced, which in turn entails an important local modification of the lattice. In the following we investigate the steps taken to generate the linear lattice optics and then to optimize the nonlinear dynamics part. The main parameters of the baseline lattice and the newly designed set-up with a single dipole source at cell-22 are reported in Table 1. A detailed description of the matching process is described below.

LATTICE MODIFICATION

Linear Lattice Re-design

The demand of a dipole source in the center of mid-straight 22 is a compromise between a large fan angle from the bending magnet, the available space in the straight and the ability at matching the modified lattice. One key point for this kind of source refers to the set-up used to extract the useful radiation from the production point, since the large fan angle makes a transporting through the downstream

* marco.apollonio@maxiv.lu.se

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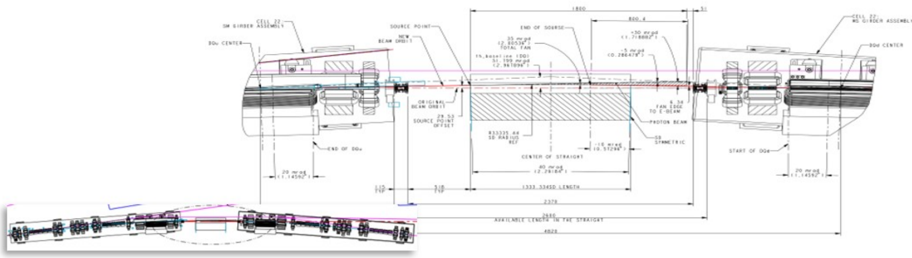

Figure 2: Technical drawing detailing cell-22 single dipole set-up. Bottom-left: inset showing a top view of cell-22 girders with the new dipole element in the mid-straight.

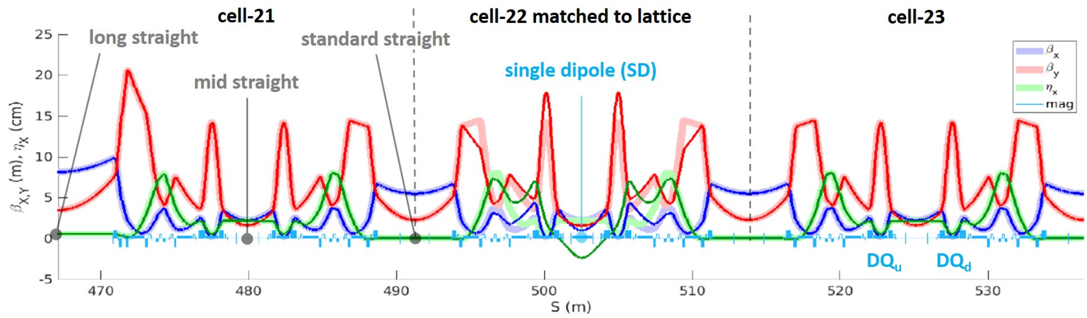

Figure 3: Diamond-II optical functions in the region around cell-22: the light colours illustrate the β_X (red), β_Y (blue) and η_X (green) for the baseline lattice. The dark colours describe the modified lattice, where a bending magnet has been introduced in the mid-straight of cell-22. The superposition of the optical functions outside of cell-22 is testimony of the good matching obtained in the re-design of the lattice.

Table 1: Diamond-II Parameters of the Baseline Lattice Compared to the Single Dipole Modification

Diamond-II	Baseline	Single Dipole
ϵ (pm.rad)	160.9	168.4
ν	(54.150, 20.269)	(54.141, 20.260)
ξ (natural)	(-67.5, -88.6)	(-67.84, -89.27)
ξ (corrected)	(2.334,2.687)	(1.206,2.2556)
α_C ($\times 10^6$)	104.14	107.55
U_0 (MeV/turn)	0.724	0.718
$\tau_{x,y,E}$ (ms)	9.6, 18.1, 16.2	9.7, 18.2, 16.4

magnets almost impossible. The solution described here is a downstream mirror system, placed at 1.134 m from the source point, with a side separation from the electron beam of 6.34 mm. This set-up would allow to capture SR within 30x30 mrad^2. The process of design of K22 single dipole solution entailed a close interplay between different groups and several iterations to reach a final solution which is visually represented by the technical drawing in Fig. 2. The matching procedure relies on a parallel swarm optimization from the code elegant [4] and redefines the gradients and some bending angles of the quadrupoles utilized as anti-bends, as detailed in Table 2. Some hardware changes were necessary as well: the QF4 elements were split into two separate families to increase the number of parameters used in the matching procedure, and length of QF8 was increased to bring the gradient within practical limits. A summary of magnet modifications is shown in Table 2. The result of the matching is illustrated in Fig. 3, where the light colors refer to the baseline lattice and the dark ones to the newly defined set-up with a bending element in the center of cell-22 mid-straight. After matching, the most noticeable effect is an increase of 7.5 pm in the natural emittance (Table 1).

Table 2: Main Changes of the Magnets in Cell-22 and the Newly Added 40 mrad Single Dipole (K22). Baseline Values Are Reported in Brackets

Magnet	K (m^{-2})	L (cm)	θ (mrad)
QF1	4.22 [4.05]	25 [25]	-
QD2	-5.07 [-4.32]	18.5 [18.5]	-
QD3	-2.64 [-3.93]	15 [15]	-
QD5	-4.26 [-5.37]	11.5 [11.5]	-
QF6	5.34 [5.91]	36 [36]	-
QF8	6.04 [7.30]	36 [25]	-
$QF4_1$	2.04 [4.83]	15 [15]	-2.62
$QF4_2$	5.57 [4.83]	15 [15]	-2.62
DQ	-2.77 [-2.775]	87.0	31.8 [51.8]
K22	-0.084	133	40.0

Non-linear Dynamics Optimisation

Once the linear lattice has been re-designed and matched to the pre-existent baseline case, attention was brought to

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the non-linear aspects of the system. Already during the matching phase and following one of the guidelines used during the design of Diamond-II, care was taken to control the phase advance in cell-22, trying to mimic the behavior of the other cells and making the new insertion "transparent" to the rest of the machine. In this respect we tried to fulfill the -I transformer condition, with a phase advance between the chromatic sextupoles of cell-22 (2.8916π, 0.93π) as close as possible to the one found in other standard cells (2.8924π, 0.9708π). The code OPA [5] was then utilized to maximize the dynamic aperture of the bare lattice, by acting on sextupoles and octupoles to minimize the tune shift with energy and amplitude (Fig. 4). Their values are reported in Table 3, together with a comparison with the baseline lattice. Note how the gradients of the non-linear elements differ inside and outside cell-22.

Table 3: Non-Linear Elements of the Single Dipole Lattice as Compared to the Baseline for Diamond-II

Magnet	Baseline	Cell-22	Outside Cell-22
		K_2 (m^{-3})	
SF1	717.153	722.857	722.867
SD1	-538.362	-618.357	-544.076
SD2	-435.481	-372.629	-435.481
SH1	62.845	90.840	66.845
SH2	-20	-60	-20
S	-137.149	-105.14	-137.149
		K_3 (m^{-4})	
OF1	-23333.3	10000.0	-23333.3

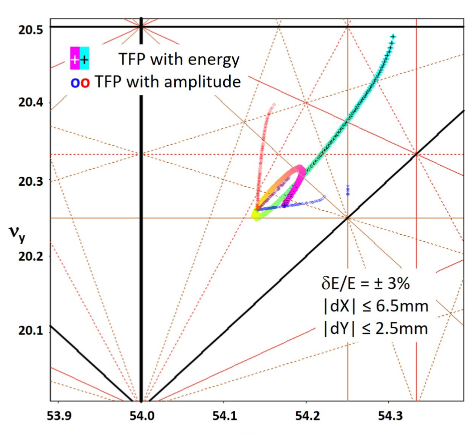

Figure 4: Tune footprint with amplitude (red-blue dots) and with energy shift (magenta-cyan crosses).

A large variation in both the horizontal and vertical tunes is particularly evident for negative energy shifts, which is a source of concern due to the crossing of potentially dangerous resonances, however a study with 20 error seeds shows that an acceptable dynamic aperture is reachable. A further improvement in the ultimate figures of merit, Touschek lifetime (LT) and an off-axis injection efficiency at x=−5 mm (IE), can be obtained by performing a scan in tune, trying to identify good working points for the new setting. These searches are illustrated in Fig. 5 where 1-seed scan points are represented by squares and few remarkable solutions are recalculated with 20 seeds: the diamond marker shows the baseline lattice point, the star is the chosen solution, the circles are other cases under consideration. Comparison between baseline lattice and SD initial and chosen solutions is reported on Table 4.

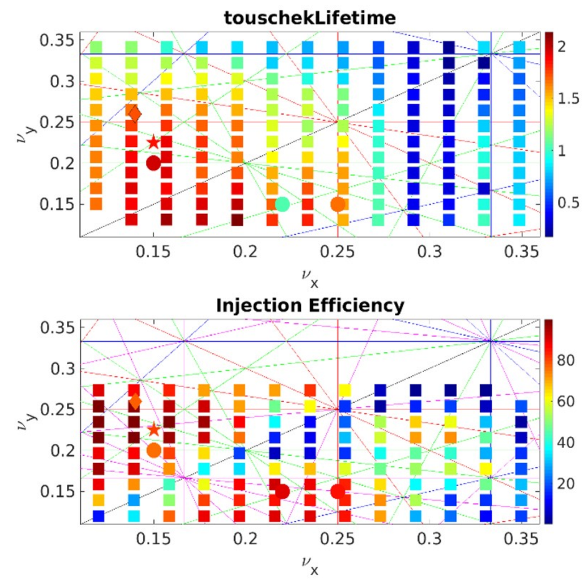

Figure 5: Tune scans to identify the best (LT, IE) for the single dipole lattice. (Top) LT scan, (bottom) IE search.

Table 4: Summary of LT and IE at −5 mm Calculations for the Main Lattices Under Consideration

Lattice	Tune	LT (hr)	IE(%)
baseline	(54.15,20.269)	1.80 ± 0.12	95.0 ± 3.33
SD start	(54.14,20.26)	1.73 ± 0.08	76.7 ± 6.99
SD scan	(54.15,20.225)	1.85 ± 0.08	80.3 ± 10.2

CONCLUSIONS

The baseline lattice for Diamond-II was modified to introduce a dipole in the mid-straight of a cell as a possible source for a broad-band beamline. Re-matching and classic optimisation procedures, followed by a tune scan on LT and IE allow to reach a set-up with a limited reduction in performance: $\delta\epsilon = 7.5$ pm, δLT = 0.05 hr, δIE = −15 %. Ongoing studies foresee the use of chromaticity scans and MOGA optimisations to reduce the gap between the baseline machine and this new lattice, especially for the injection efficiency.

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