CONCEPTS FOR A LOW EMITTANCE-HIGH CAPACITY STORAGE RING FOR THE DIAMOND LIGHT SOURCE

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Abstract

The Diamond Light Source is investigating several paths for a possible machine upgrade to Diamond II. The exercise is driven by a joint assessment of the science capabilities opened by a very low emittance ring and the machine design that will underpin them. The consultation is made on a beamline-by-beamline basis and has highlighted a significant preference for lattices that combine both a low emittance and large capacity for IDs.

INTRODUCTION

The Diamond Light Source has recently identified a number of technical and scientific developments for the facility to maintain competitiveness in the next 10 years [1]. At the core of this vision is the improvement of the source performance underpinned by the replacement of the existing storage ring with a lower emittance ring upgrade. In this framework, Diamond Science and Technical division have a lunched a series of studies aimed at the investigation of the possible options for lattice upgrade and the identification of the new science opportunities that this upgrade will enable.

A closer evaluation of the benefit on a beamline by beamline bases has given the opportunity to establish a close link between users and machine designers to try to include the beamline scientist input in the machine design as much as possible. This paper reports about the present status of the upgrade of machine and source design.

THE DDBA/DTBA CONCEPT

Several options for MBA lattice have been investigated in the past [2]. Most of the initial effort has concentrated on a lattice based on a 4BA cell. A noticeable result of these studies is the possibility of modifying the 4BA cell by introducing an additional mid-cell straight section while maintaining a very small emittance. The modified cell effectively looks like a double-double bend achromat and has been named DDBA. This new design produces a 10-fold reduction of the emittance to 270pm and doubles the capacity of the ring by doubling the number of straight sections. The layout and optics functions of the DDBA cell are shown in Fig. 1.

The ratio between the machine circumference and the straight section is 50% from the original 37% of the existing Diamond DBA lattice. It is clear that a higher number of bending magnets per cell will reduce the emittance even further: a 5BA lattice can generate 140 pm, but again the DA optimisation is correspondingly more complicated. The flexibility of the DDBA has revealed to be a valuable asset in the lattice choice.

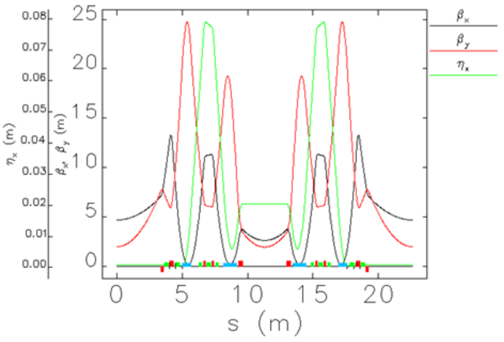

Figure 1: The DDBA cell.

Progressing with the optimisation we have investigated, in collaboration with the ESRF, the possibility of adapting the DDBA concept to the ESRF-EBS cell [3]. This has been simply achieved by removing the central dipole form the 7BA cell of ESRF-EBS thereby generating a cell with 6 bending magnets and re-matching the optics. The cell has been named double triple bend achromat (DTBA), in analogy with the original DDBA and the ring has an emittance of 120 pm. The layout and optics functions of the DTBA cell are shown in Fig. 2 while the main parameters are reported in Tab. 1.

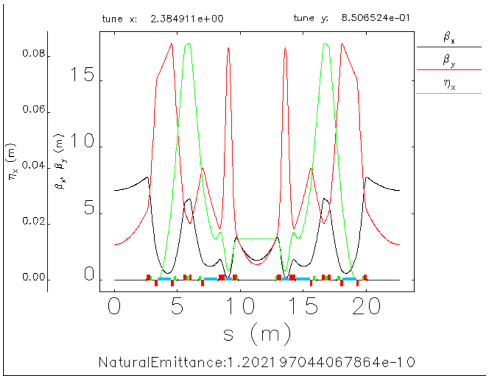

Figure 2: The DTBA cell.

Details of the cell layout and optimisation results are reported in a companion paper [3]. Such a cell combined the best of both featured of the ESRF-EBS, with the longitudinal gradient dipole and the dispersion bump, and the additional straight section at the middle of the cell. The initial optimisation of the cell show that the optic function can be kept below 20 m, the natural chromaticity is comparable to the one of the existing diamond lattice and the paring of the sextupoles in the dispersion bump to odd multiple of π (3π in H and close to π in V) is very effective in compensating the driving terms. The

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nonlinear dynamics optimisation shows that a DA of 10 mm is within reach.

Table 1: Main Parameters of the DTBA Cell

	Diamond	Diamond II
Energy	3 GeV	3 GeV
H emittance	2700 pm	120 pm
V emittance	8 pm	8 pm
Current	300 mA	300 mA
Bunch length	3 mm @ 0 mA	1 mm @ 0 mA
Nat. chroms.	-90/-54	-130/-70
e^- size (h,v)	124μm/3.5m	24μm/3.5μm
e- div. (h.v)	24μrad/2μrad	5μrad/2μrad

BRIGHTNESS, FLUX AND COHERENCE

A first assessment of the source performance was made on the basis of the electron beam sizes reported in Tab.1, taking into account the full suite of ID and their wavelength range. The beamlines can be broadly subdivided in ID beamlines for hard X-rays or soft X-rays, wiggler and bending magnets beamlines.

ID beamlines: the source improvement for hard X-rays can be obtained by comparing the brightness as given by the tuning curve of one of the CPMU devices used in the existing Diamond ring. The CPMU has 116 periods with λ_u = 17.7 mm and maximum K =1.7 for 5 mm gap. In Fig. 3 we compare the brilliance of the first seven harmonics, for the existing Diamond lattice and the DTBA. In both cases the vertical emittance is 8 pm.

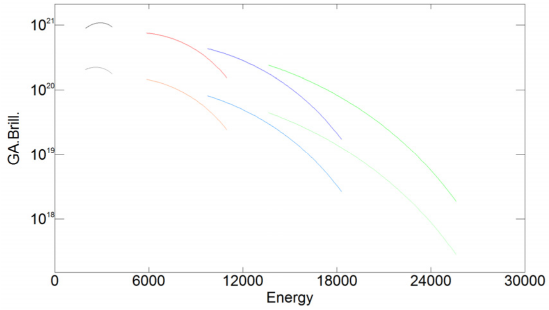

Figure 3: Comparison of brill. (ph/s/0.1BW/mm^2/mrad^2) for the Diamond lattice and the Diamond II DTBA (ID data in text).

The flux density improvement shown in Fig. 4 is less striking as expected since the emittance reduction does not impact the number of photons emitted but modifies their phase space distribution.

However notice that the monochromatic flux is much more concentrated as shown from the flux through an rectangular angular aperture of 40*40 μrad^2 located at 30m downstream the ID, reported in Fig. 5 where it appear clear that the flux in the harmonics is much better collimated in Diamond II DTBA.

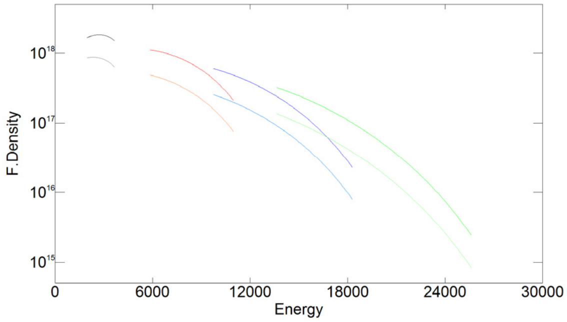

Figure 4: Comparison of flux (ph/s/0.1%BW) density for the Diamond lattice and the Diamond II DTBA. Same ID as in Fig. 3.

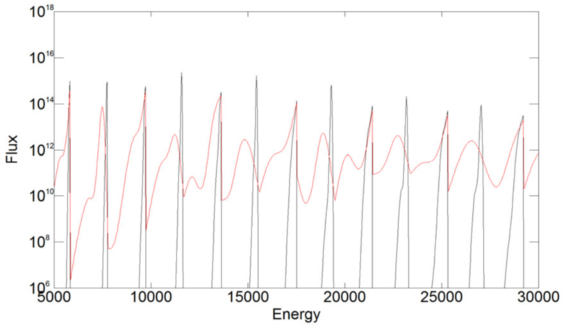

Figure 5: Comparison of flux (ph/s/0.1%BW) through a given aperture for Diamond (red) and Diamond II DTBA (black). Same ID as in Fig. 3.

The coherent fraction as measured by the ratio

$$F = \frac{(\lambda / 4\pi)^2}{\Sigma_x \Sigma_{x'} \Sigma_y \Sigma_{y'}} \qquad (1)$$

is also noticeably improved by the lattice upgrade. It is worthwhile observing [4] that the inclusion of the energy spread effects has important consequences although it is often neglected. Here we have considered the parameterisation of the photon size and divergence as a function of the energy spread as reported in [5]. The coherent fraction and the impact of the energy spread is reported in Fig. 6.

Figure 7 (top) shows the photon phase space at 1 Angstrom, and the effect of the convolution with the electron phase space. Figure 7 (bottom) gives the same information including the effect of the energy spread on the photon beam size and divergence. It is clear that the electron optics functions are not yet matched to the photon phase space and this effect is significantly exacerbated when the effect of the energy spread is included. As far as soft X-rays beamlines are concerned, the gain in brightness and coherent fraction is reduced as compared to hard X-rays due to the proximity to the diffraction limit at those wavelengths. However a factor of about 4 in brightness increase is still visible down to 250 eV.

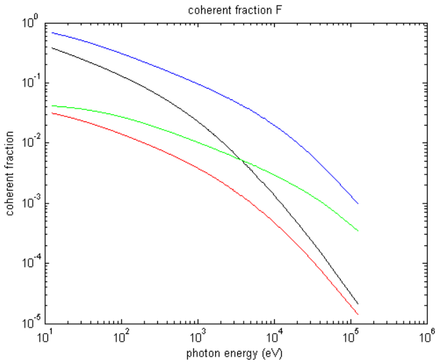

Figure 6: Comparison of coherent fraction at different wavelengths between Diamond (black) and Diamond II DTBA (blue). The effect of the energy spread is also shown (green and red respectively).

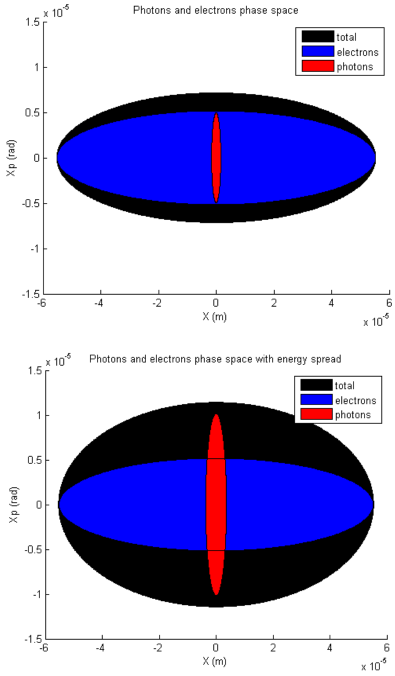

Figure 7: (top) phase space of photon beam at 1 Angstrom and electron beam phase space; (bottom) same info including the effect of the electron beam energy spread.

Wigglers: Diamond II DTBA will continue to operate wiggler sources. The comparison in flux for I12 is reported in Fig.8 and shows no significant differences.

Bending magnets: Diamond operates seven bending magnet beamlines, taking radiation from the second dipole in the DBA cell. All versions of the Diamond upgrade lattice have evident implications for such beamlines due to the changes in the characteristics of the main dipoles dictated by the beam dynamics optimisation. The 1.4 T dipole field of the existing Diamond ring is lowered to 0.8 T in the DDBA cell, resulting in a decrease of the critical photon energy from circa 8.4 keV to 4.8 keV [6]. This effect is seriously detrimental both in terms of photon flux and brightness for the hard X-rays BM beamlines doing spectroscopy, generally working up to 3 times the critical energy. In the DTBA cell the bending magnets aligned closer to the bending magnet ports are gradient magnet with a lower magnetic field (below 0.9T). For this reason the lattice choice has been strongly steered towards MBA cell with M even and an additional straight section in the middle of the cell. The additional 3 m straight offers the possibility of installing dedicated sources or insertion devices e.g. tailored to the specific science community currently satisfied by existing BM beamlines. A first assessment of the Diamond BM beamline requirements showed that BioSAXS B21 could profit from an undulator or a superbend, CoreXAS B18 from a 3-poles wiggler (3PW) providing more flux and broader spectrum at harder X-rays. MicroIR B22 and CD B23 will prefer special low-critical energy source, e.g. a low magnetic field dipole/3PW wiggler to achieve a diffraction limited source within the new machine tighter constrains in front end size. Optics B16 will benefit from a possible combination of both wiggler and undulator in a canted arrangement, to satisfy both flux and brightness needs. In all cases, the new lattice polygonal has to take into account the existing BM beamline constrains, e.g. hutches, optical axis position and angle, to be feasible.

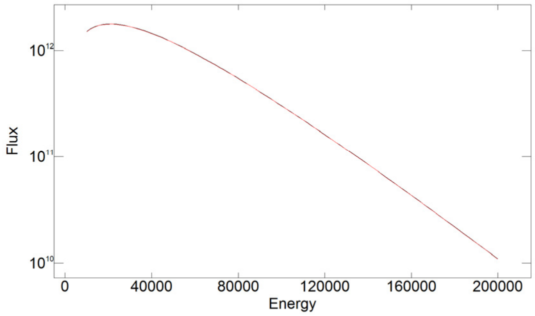

Figure 8: Flux density (ph/s/0.1%BW/mrad^2) comparison for the I12 wiggler for Diamond (black) and Diamond II (red).

CONCLUSIONS

The design of the Diamond upgrade is well on the way as a joint effort between the machine physicists and the beamline scientists. Further work will continue to cater for the specific needs of the beamlines as much as possible, notably in the maintaining the straight sections untouched, allowing for special optics beamline with double mini-beta in I09 and I13, and investigating the options for maintaining time resolved operating modes. The conceptual design report should be ready by 2017.

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