

PLANS FOR THE GENERATION OF SHORT RADIATION PULSES AT THE DIAMOND STORAGE RING

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Abstract

Diamond is a third generation light source under commissioning in Oxfordshire UK. In view of the increasing interest in the production of short radiation pulses, we have investigated the possibility to operate with a low-alpha optics, the use of a third harmonic cavity for bunch shortening and the implementation of a crab cavity scheme in the Diamond storage ring. The results of the initial accelerator studies will be described, including the modification of the beam optics, non-linear beam dynamics optimisation and choice of RF parameters for the crab cavity operation. The expected performance of these schemes will be summarised.

INTRODUCTION

The Diamond storage ring is a DBA lattice with non-zero dispersion in the straight sections, designed to operate with a nominal emittance of 2.7 nm. It is made of 6 identical super-periods, each with three short straight sections (5.3 m) and one long straight (8.3 m), giving 24 cells total with 22 straight sections available for Insertion Devices (IDs). The Diamond storage ring has reached the commissioning phase [1] in May 2006.

The possibility of different operating modes for the generation of short radiation pulses from the storage ring has been taken into account already at this early stage in the development of the project. Several options are currently under investigation: the operation with a low- α optics and the use of a 3rd harmonic cavity in bunch shortening mode allow operating with bunches of reduced length, thus producing shorter radiation pulses. A third option is based on the well known concept of crab cavities[2], where short radiation pulses are produced by means of a chirp in the vertical momentum of the beam followed by the compression of the radiation pulse itself rather than the electron bunch length.

In what follows we describe the application of the three schemes to the Diamond storage ring and their expected performance.

LOW- α OPTICS

In a storage ring the bunch length at small current depends on the momentum compaction factor α , the RF voltage V_{RF} and frequency f_{RF} and the relativistic γ as

$$\sigma_t \propto \sqrt{\frac{\alpha \gamma^3}{\omega_{RF} V_{RF}}}$$

Low- α optics were developed for the Diamond storage ring using ELEGANT [3] and BETA [4] to optimize the ten quadrupole families and the eight sextupole families of the storage ring. Using the ten quadrupole families, it is possible to reduce the momentum compaction to any small value without losing the desired features of the nominal optic, such as the low-beta section in the short straights and high horizontal beta at the injection point, while simultaneously controlling the betatron tunes. Linear optics with weaker horizontal focussing than the nominal lattice generates a lower natural horizontal chromaticity and requires, generally, weaker sextupoles to correct the chromaticity. This helps significantly the subsequent optimization of the non-linear lattice parameters. Fig. 1 shows the optics functions of the proposed low- α optic for the Diamond storage ring.

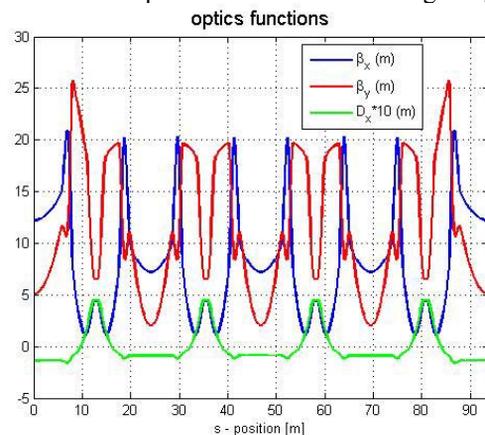


Figure 1: Low- α optic: $\alpha = 10^{-6}$; working point ($Q_x = 21.22$; $Q_y = 12.36$), emittance $\epsilon_x = 36.2$ nm

Three sextupole families were used to correct the chromaticity and reduce the second order momentum compaction nearly to zero. The remaining five sextupole families were used to keep a large on-momentum dynamic aperture for injection, control higher order terms in the dependence of the momentum compaction factor with off-momentum energy and to provide an acceptable momentum aperture. Since we do not expect to store a large current per bunch in this mode, the requirements for off-momentum dynamics are mainly dictated by the injection efficiency rather than Touschek lifetime. Hence, in this phase of the optimization we set our target to a momentum aperture larger than 2%. A satisfactory matching could be obtained only by reversing the polarity of a sextupole family, which implies the need of a hardware upgrade since Diamond sextupoles have currently unipolar power supplies.

Increasing the current in the low- α optics is limited by the onset of the so called bursting instability determined by the CSR emission from the bunch. Below the current bursting threshold, the synchrotron radiation emitted is very stable and ranges from THz to hard X-ray. Above the bursting threshold the THz radiation pulses become noisy and the bunch starts to lengthen above the zero-current value, reducing the benefits of the low- α configuration. The bursting current threshold can be estimated according to the equation [5]

$$k\sigma_z \leq 2\Lambda^{3/2}, \quad \Lambda = \frac{N_e r_0 \rho}{\sqrt{2\pi\sigma_z \sigma_e^2 \alpha \gamma R}}$$

where k is the wavenumber of the radiation that generates the instability, σ_z is the bunch length, N_e is the number of electron per bunch, r_0 is the classical electron radius, ρ is the bending radius, σ_e is the energy spread, γ is the relativistic factor and R the average accelerator radius. Following BESSY-II experience [6], where $k\sigma_z \approx$ few units, the current threshold for the Diamond storage ring is about 10 μ A per bunch. Depending on the filling pattern, the repetition rate of these radiation pulses could vary from 530 KHz (1 bunch, 1 ps, 10 μ A) to the normal repetition rate of the ring, i.e. 500 MHz (936 bunches, 1 ps, 10 mA). Despite the lower circulating current, the synchrotron emission in the THz spectral range is larger than in normal operation. X-ray emission is about 30 times less intense than in the nominal operation of the ring at 300 mA. Also the brightness is reduced due to a higher horizontal emittance of the beam in the low- α mode.

HARMONIC CAVITIES FOR BUNCH SHORTENING

The use of a 3rd harmonic cavity for bunch lengthening [7] is being considered for Diamond. In particular, a system consisting of a passive SC RF cavity operating at 1.5 GHz of the SUPER-3HC type developed at ELETTRA/SLS [8] is being studied.

Such a cavity can also be operated passively in bunch shortening mode. Tracking studies were performed with a 2D model of the longitudinal dynamics in the presence of a broad band impedance $Z_{||}/n = 0.2 \Omega$, and a 3rd harmonic cavity detuned in shortening mode. The results are shown in Fig. 2. The reduction in bunch length is only about 30%, obtained with an induced voltage of 1.1 MV in the 3rd harmonic cavity, however the shortening effect is kept at all currents. The Touschek lifetime is reduced by the same factor. These results show that 7 ps pulses can be achieved with a 100 μ A current per bunch, above which the bunch lengthens due to potential well distortion. The repetition rate of these radiation pulses could vary from 530 KHz (1 bunch, 7 ps, 100 μ A) to the normal repetition rate of the ring, i.e. 500 MHz (936 bunches, 7 ps, 94 mA). Given the lower circulating current, the predicted

synchrotron radiation is about 3 times less intense than in the nominal operation of the ring at 300 mA.

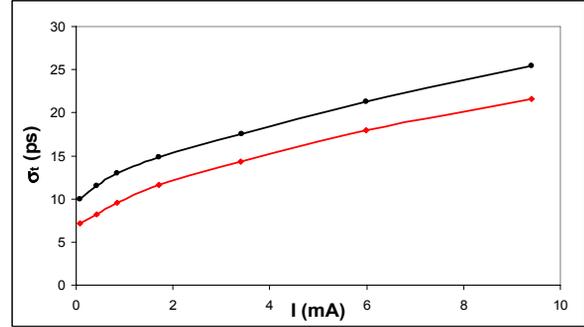


Figure 2: Bunch lengthening curves with single bunch current: black without 3rd HC, red with 3rd HC in shortening mode

The combined use of a 3rd harmonic cavity and a low- α optics is under investigation and appears to be very promising since the bursting instability parameter Λ depends on the inverse of the RF gradient [6] and the low- α operation could benefit from a higher RF voltage gradient.

CRAB CAVITY SCHEMES

The use of two transverse (vertically) deflecting RF cavities – crab cavities – in synchrotron light sources to generate short X-ray pulses has been proposed by A. Zholents et al [2]. In this scheme, a first crab cavity generates a correlation between the longitudinal position of the particles in a bunch and the vertical momentum; a second RF cavity cancels the effect of the first one. In this way different portions of the bunch emit in different directions and a short pulse can be extracted with a system of slits or created with optical compression. To obtain a first-order cancellation of the effect of the cavities' effect on the beam dynamics, the two crab cavities are separated by a phase advance that is an integer multiple of π . In this way the synchrotron radiation and the electron beam properties are ideally affected only between the two crab cavities. The beamlines in between the two cavities can profit from the reduced X-ray pulse duration while the rest of the users are in principle unaffected. The cancellation, however, is never perfect and the residual effect of the crab cavity kicks has to be estimated with numerical tracking [9]. These studies also estimate if a significant pulse compression can be achieved with realistic RF parameters for the crab cavities.

The nominal Diamond storage ring lattice is well suited for the installation of the crab cavities since the nominal phase advance between two adjacent straight sections is π and therefore minimal modification to the optics are sufficient to achieve the vertical kick cancellation.

Numerical studies performed with ELEGANT allowed choosing the RF frequency and RF voltage of the crab cavities: operating with 3 GHz, 6th harmonic of the main RF frequency, the RF voltage is still linear over a range of

20-30 ps bunch length and the compression is not spoiled by non-linearities in the RF wave. The RF voltage value is limited by the condition that too large a kick can generate losses in the ID vertical aperture: losses start to be significant at 1.5 MV, therefore a value of 1.25 MV was deemed to be satisfactory. The maximum angle generated is 0.42 mrad.

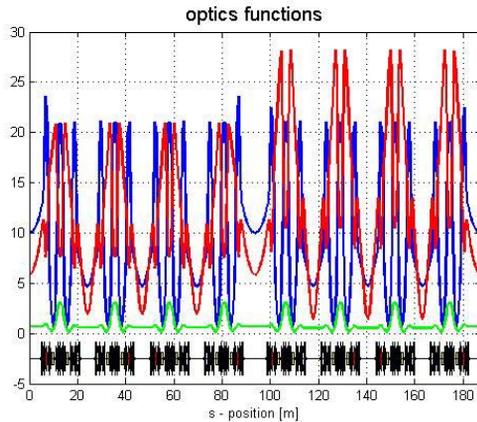


Figure 3: Modified optics to generate a 4π vertical phase advance between the crab cavities located in two long straight sections.

The effect of the lack of perfect cancellation of the crab cavity kicks was estimated with ELEGANT and the numerical simulations shows only a modest increase of the beam emittance. Tracking studies were performed with Tracy-II [10] to evaluate the variation of the Touschek Lifetime induced by this modified optics. The momentum aperture along the ring does not vary significantly with respect to the nominal optics, however this calculation does not include the effect of the crab cavities themselves. Version 16 of ELEGANT is able to compute the momentum aperture including the crab cavity and is under test. RF cavity design issues, including LOM/HOM damping, tuning, and low level control will need to be addressed.

With these RF parameters the radiation pulse length and the transmission after a system of slits and a compression optics was calculated. The code ELEGANT allows the optimization of the optical system parameters. The results of the simulations are reported in Fig. 4 and Fig. 5.

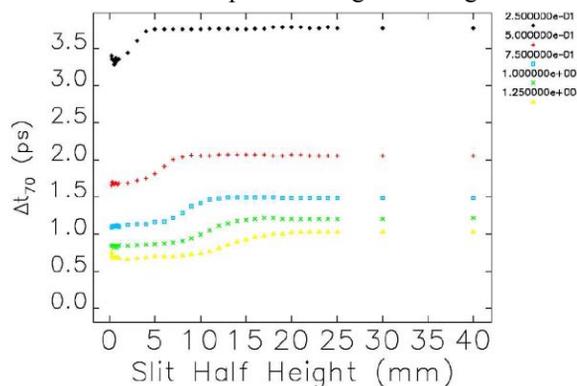


Figure 4: Achievable compression for different slit openings and crab cavity voltages.

The achievable bunch length for 1.25 MV can be shorter than 1 ps and transmission can be as high as 80% excluding optics losses. These short pulses are available with the filling pattern achievable during normal operation of the beam, i.e. from 1 bunch with 530 KHz, and current up to 10 mA, to 936 bunches with 500 MHz rep rate and 300 mA total circulating current.

In the present scheme, with the crab cavities located in two long straight sections, there will be three beamlines which will benefit of the vertically tilted beam. Alternative locations are easily envisaged.

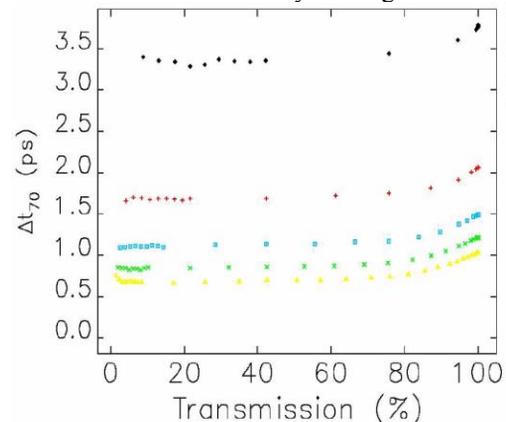


Figure 5: Transmission for different slit openings and crab cavity voltages. Same optic compression as in Fig. 4.

CONCLUSION

Several schemes for the production of short radiation pulses are under investigation at the Diamond storage ring. The implementation of low- α optics requires only minor hardware modifications and can be pursued after the end of the commissioning period. The installation of a 3rd harmonic cavity for bunch lengthening is under consideration but not yet funded. The crab cavity scheme is rather new for synchrotron light sources and requires some R&D especially given the RF cavity requirements. However these first investigations show that it is well suited to the Diamond storage ring. Finally, one of us (RB) would like to thank G. Wuestefeld of BESSY for many stimulating discussions on low- α optics.

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