EXTRACTION ARC FOR FLASH II

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Abstract

FLASH II is an extension of FLASH, an FEL user facility at DESY, Hamburg. It uses the same linear accelerator. Fast kickers and a septum will be installed behind the last superconducting acceleration module of the FLASH linac, providing the possibility to distribute beam to the FLASH undulator beamline and through the new extraction arc. It is foreseen that at the end of the extraction arc for FLASH II the beam can be split again into two separate beamlines: The main beamline hosting undulators for SASE and space for HHG seeding, the other beamline might serve later a plasma wakefield experiment or an additional long wavelength SASE source. The extraction arc was designed to mitigate the effects from coherent synchrotron radiation (CSR) like emittance and energy spread growth. The extraction arc for FLASH II places also demands on the existing FLASH beamline which are taken into account. The lattice optimization of the arc was done using the program ELEGANT. Start to end simulations for different bunch charges including FEL simulations with GENESIS were carried out to show the feasibility of the lattice design for the extraction arc.

INTRODUCTION

The existing single-pass high-gain SASE FEL FLASH (Free-electron LASer in Hamburg) at DESY, Hamburg [1] delivers photons in the wavelength range from 4.1 nm to 44 nm. The photons generated by six fixed-gap SASE-undulators can be delivered to five experimental stations in the FLASH experimental hall. FLASH II was planed and is now under construction to increase the beam time for users [2]. Three fast kickers and a DC Lambertson-Septum to be installed behind the FLASH linac give the possibility to distribute the beam either to the existing beam line or to the new extraction arc. At the end of the arc there will be a pulsed bend which allows to steer the beam away from the main beam line, which hosts variable gab undulators for SASE and space for HHG seeding, or to a 3rd beamline serving a proposed plasma wake field experiment.

The variable cap undulators in the new beamline will have a segment length of 2.5 m and a period of 31.4 mm. The total number of segments is 12. The proposed wavelength range for this undulator beamline is 4 nm - 80 nm for SASE and 10 nm - 40 nm for HHG seeding.

SPECIFIC REQUIREMENTS TO THE BEAM TRANSPORT

The challenge for the extraction arc is to fulfill several conditions given by the building environment and by the beam optics. Besides of little free space for additional elements in the existing FLASH installation, the new photon beamline downstream the undulators has to cross PETRA3, a brilliant storage-ring-based X-ray radiation source [3], at a dedicated place which fixes the extraction angle at 12 degree. In addition, the maximum length of the new tunnel is also limited by the PETRA3 accelerator.

In order to mitigate CSR-effects, the beta functions have to be small in all strong horizontal bends [4] [5]. Further requirements on the beam optics are a closed dispersions in both planes and zero momentum compaction.

LATTICE OPTIMIZATION

In an earlier solution for this extraction arc realized with bending magnets of 7, 1.5 and 3.5 degree and a negative dispersion in the second bend to archive zero momentum compaction [2], the impact of the beam transport on the beam quality was too strong and not suitable for the new beamlines. It was necessary to reduce the strength of the quadrupole magnets between septum and the next bending magnet to improve the beam quality. However these strong quadrupole magnets were necessary to get the negative dispersion in the second bend. The idea for the new extraction arc presented in this paper was to implement a weak reverse bend downstream the septum at a location with positive dispersion which allows to archive zero momentum compaction.

The final solution for the extraction has now deflection angles of 6.5, -0.9, 3.2 and 3.2 degree. A top view of all magnet positions can be found in Fig. 1. The program used for all optimizations and for particle tracking was ELEGANT [6].

The new optics design shows small beam waist in all strong horizontal bends as necessary to mitigate the coherent synchrotron radiation effects. The required vertical offset for the Lambertson-septum is achieved with 3 kickers upstream of the septum. The kick is increased by two out of the three quadruples between kickers an septum which are passed with a vertical offset. The third quadrupole magnet deflects the beam back to straight trajectory. These quads provide the beam waist in the septum. The vertical dispersion caused by the kickers is closed with two vertical bends at the end of the extraction arc. In horizontal plane, closed dispersion is achieved. Three sextupole magnets in the extraction arc are required to close the second order vertical dispersion.

Zero R56 is obtained by use of the reverse bend and proper characteristics of the dispersion function. Plots of the betatron functions, the dispersion functions, the momentum compaction function as well as for the vertical beam center position are presented in Fig. 2.

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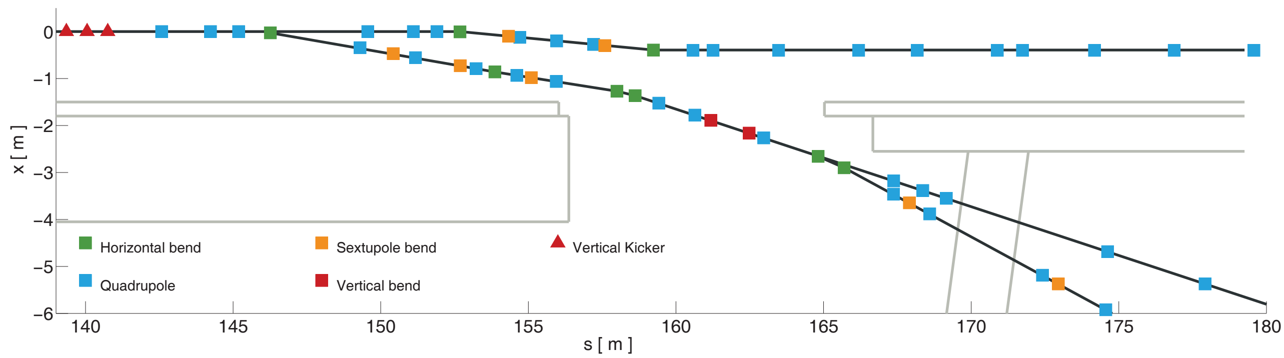

Figure 1: This plot shows a top view of FLASH II and the straight FLASH beamline. The building walls are sketched in Grey color.

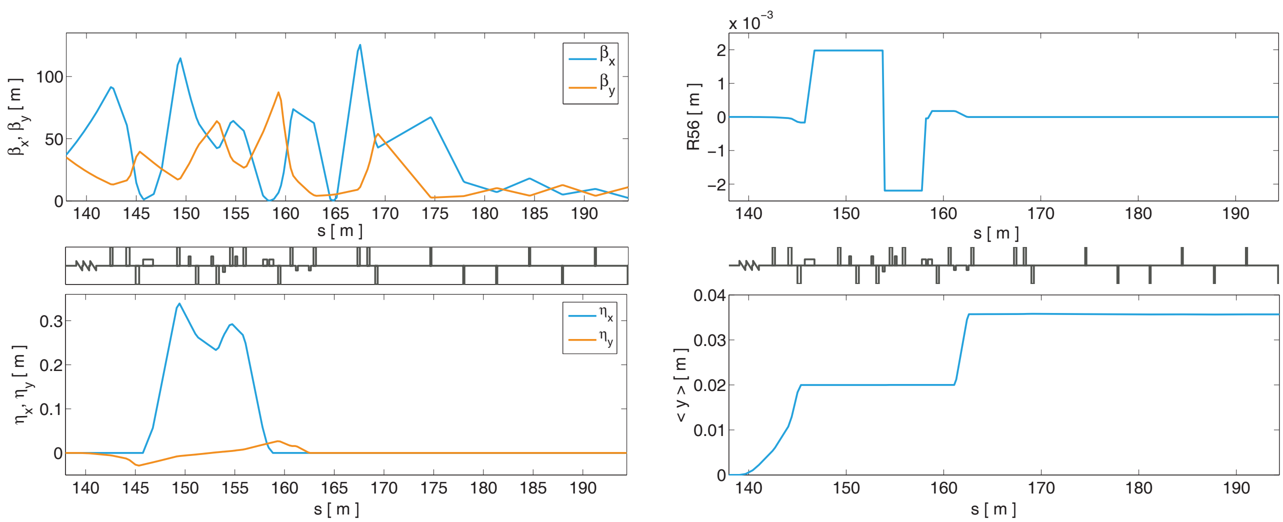

Figure 2: Optic functions for the new extraction arc for FLASH II. The upper plots show the betatron functions and the first order momentum compaction (R56) and the lower plots the dispersion and the vertical beam center position.

START TO END SIMULATIONS

To verify the usability of the new lattice layout, start to end simulations were carried out. For this simulations, bunches with an energy of 1 GeV and with charges of 20 pC, 100 pC, 250 pC and 500 pC were tracked trough the linac and the extraction arc including space charge and coherent synchrotron radiation effects. Finally the bunches were used for single shot FEL simulations using GENESIS [7]. In Fig. 4 one can find the evolution of the projected normalized emittances along the extraction arc for all charges mentioned above and for both planes. As one can see in the plots, some of the horizontal emittances are slightly decreasing. This is due to an advantageous interaction between arc beam optics and bunch shape.

The more significant statement whether the new extraction arc is feasible for serving an undulator beamline or not can be found by evaluating the FEL-simulations presented in Fig. 3. The current distributions and photon pulses in the upper plots as well as the single shot spectra in the lower plots show the situation after an undulator length of 18 meters. This distance was chosen because FEL-simulations showed saturation at this position for all bunch charges.

The peak current before entering the new extraction arc was around 2.5 kA for all distributions. The deviation between the initial peak value and the maximum current shown in the plots points to the second order momentum compaction (T566) which is not equal to zero. This can lead to a reduction or an increase of the peak current depending on correlations with the particle distribution in the longitudinal phase space. The double peaks of the current distributions with 20 pC and 100 pC suggest that as well.

Regarding the photon pulses, one can see that the three smaller charges show pulses with a FWHM length of around 1-2 μm. The wavelength of the photons for the charges of 100 pC, 250 pC and 500 pC is about 18.6 nm as expected. The slightly shorter wavelength for the 20 pC case can be explained by a higher energy of the lasing slice compared to the other bunches.

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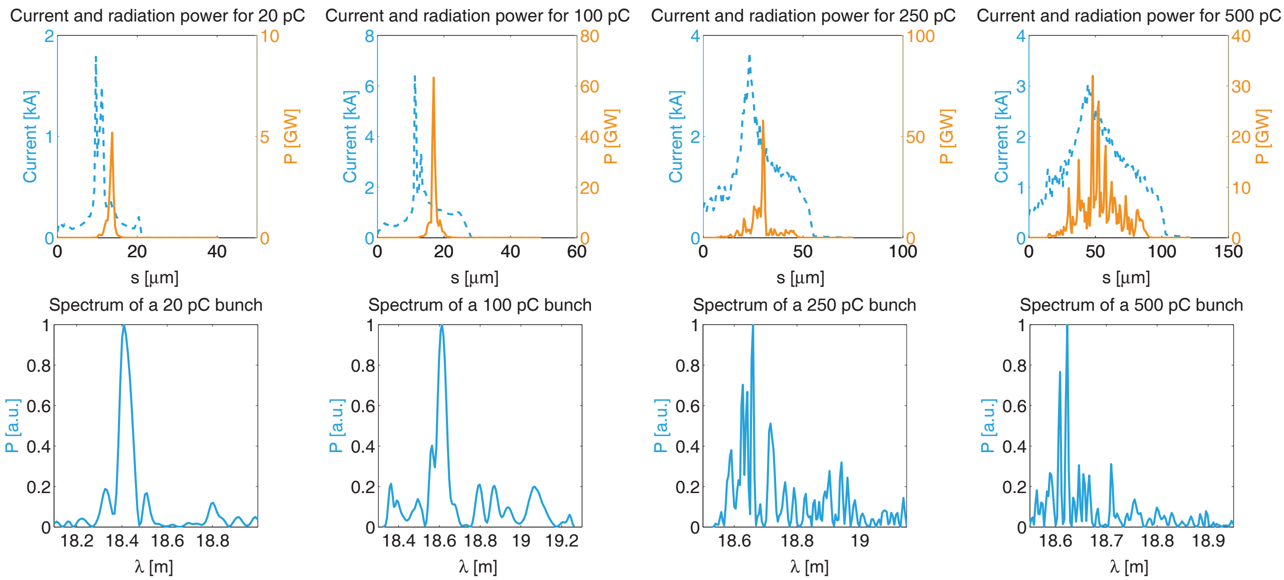

Figure 3: These plots show the results of the single shot FEL simulations with GENESIS. The bunches used for these simulations were tracked through the linac and the extraction arc for FLASH II. In the upper line one can find plots of the current distribution along the bunch and the shape of the photon pulse. The plots in the lower line show single shot spectra.

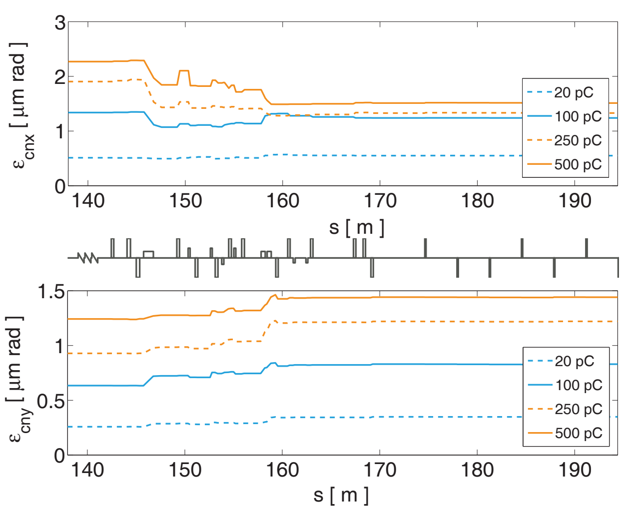

Figure 4: Projected normalized emittances evolution within the extraction arc.

CONCLUSIONS

The new extraction arc for FLASH II meets all conditions which were imposed on the extraction lattice. The presented lattice layout fits into the new tunnel restricted by the building environment and there is enough space for SASE undulators as well as for HHG seeding. Both, the horizontal and vertical first order dispersion is closed at the the end of the extraction arc and also the first order momentum compaction R56 zero as required. Horizontal beam waists in the horizontal bending magnets mitigate emittance growth due to coherent synchrotron radiation effectively. The used set of bending magnets leads to the necessary deflection of 12 degree for the new beamline. Also the extraction point for the beamline serving electrons to the proposed third beamline, the pulsed bending magnet, is considered. The start to end simulations showed that there is no increase of the projected normalized emittance in both planes for all different bunch charges. Furthermore, the single shot FEL-simulations showed short photon pulses within the expected wavelength range. The results of the start to end simulations confirm the applicability of the new extraction arc for FLASH II.

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