DESIGN OF THE SWISSFEL SWITCHYARD

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Abstract

The SwissFEL facility will produce coherent, ultra-bright, and ultra-short photon pulses covering a wavelength range from 0.1 nm to 7 nm, requiring an emittance between 0.18 to 0.43 mm mrad. In order to provide electrons to the soft X-ray beam line of SwissFEL a switchyard is necessary, which will divert the electron beam, with an energy of 3.4 GeV, after the first set of accelerating structures. This switchyard has to be designed in such a way to guarantee that beam properties like low emittance, high peak charge and small bunch length will not be spoiled. In this paper we present two possible schematics for the switchyard and also discuss the constraints on the kicker-septum set, on misalignments and on charge fluctuation.

SWITCHYARD DESCRIPTION

The switchyard for SwissFEL [1] diverts the beam coming from Linac 2, with an energy of 3.4 GeV, to the long wavelength undulator (Athos beamline). At the switchyard entrance a fast kicker followed by a septum magnet deviates the second of the two bunches accelerated in the Linac 2. This second bunch will then be further deviated towards the Athos beamline while the first bunch continues straight towards Aramis. In the present set-up of the switchyard, its total length is 77 m and the separation between the Athos and Aramis beamlines is about 4 m, with a net bending angle equal to zero, making the two beamlines parallel to each other, as shown in Figure 1. In the transport line, the central section has 9 m which should allow for the transport of heavy equipment to the Linac area and there is also is enough space for collimators in between the quadrupoles all along the switchyard. This design has two almost identical double-bend achromatic (DBA) sections and each section has a total bending angle of about 4^o. A central dipole is inserted in the center of each double bend, a ”micro-bend”, and is used only to adjust the value of R_{56} in order to make the sector also isochronous.The next section shows the two possible designs for the switchyard regarding how the bunch separation is performed. Since the two lattices share the same type of symmetry and also its main characteristics a more general discussion about both lattices is given later on.

Kicker and Septum

SwissFEL will work in double bunch mode with a bunch time separation of 50 ns and a repetition rate of 100 Hz. The first bunch will feed the hard X-ray beamline (Aramis)

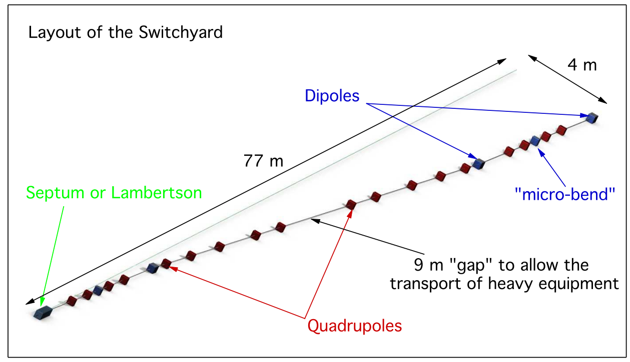

Figure 1: Switchyard general layout.

while the second one will go through the switchyard to the soft X-ray line (Athos). In order to separate the beam for the soft x-ray beamline a resonant kicker [2] will be used together with either a septum pulsed magnet or a Lambertson magnet. The set horizontal kicker and septum has the advantage of not creating any vertical dispersion, however the constraints on the septum shot-to-shot jitter may create technical difficulties for its manufacture. Another possibility is to use resonant kickers to deflect the beam in the vertical direction and use a DC Lambertson magnet to separate it horizontally [3], this setup has the advantage of introducing much less noise on the beam but on the other hand creates vertical dispersion that must be taken care of in the switchyard.

Horizontal Deflection

In the case of horizontal separation, a set of 3 kickers are placed at an average distance of 10 m from a pulsed septa. The lattice functions are shown in Figure 2. In this case there is only horizontal dispersion and the switchyard lattice is quasi-symmetric. The Septum and the first dipole bending angles are -1.97^o and the second set of dipoles bending angles are 1.92^o and the ”micro-bending” angles are 0.18 and -0.08, respectively.

Vertical Deflection

In the case of vertical separation, a set of 3 kickers are placed at a distance of 14 m from a DC Lamberston magnet. The lattice functions are shown in Figure 3. In this case the Lambertson is rotated by an angle of 1.6^o with respect to the longitudinal axis, so that the switchyard is parallel to the horizontal plane. The lattice functions are symmetric and mirrored with respect to the center of the switchyard and the vertical dispersion is maximum at a point of

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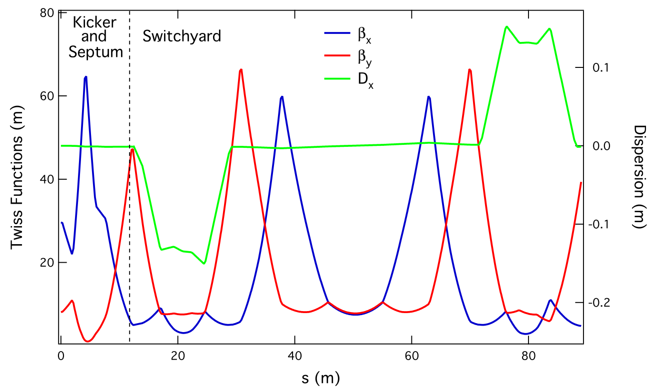

Figure 2: Twiss functions for the case with horizontal separation.

zero horizontal dispersion. The Lambertson and all three dipole horizontal bending angles are $\pm 2^o$ and the "micro-bending" angles are $\pm 0.08^o$.

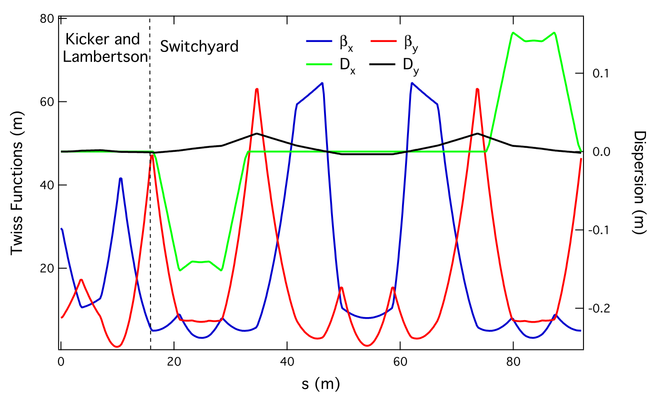

Figure 3: Twiss functions for the case with vertical separation.

Common Lattice Design

For both lattices studied the Twiss functions in the two bend sets are approximately the same, so that kicks due to coherent synchrotron radiation (CSR) act in opposite directions and, by adjusting the phase advance between them, we can compensate for the emittance dilution caused by CSR. The maximum dispersion is 0.15 m in the double-bend sections and, considering a total energy spread in the beam of 0.1%, the maximum beam size in the switchyard is 160 μm (1 sigma rms) in the horizontal plane, and is dominated by dispersion. In the transport section, the maximum beta function is 60 m in both planes which yields a maximum beam size of 56 μm in the vertical and 62 μm in the horizontal direction and for the case with vertical dispersion, a maximum vertical beam size of 64 μm. To keep the bunch length constant throughout the switchyard, the dipoles parameters were chosen so that R_{56} and T_{566} were as small as possible and for the two lattices shown in Figures 2 and 3, their values are: $R_{56} = 1.8\ \mu m \approx 0$ and $T_{566} = 31$ mm. The amount of bunch length variation in the switchyard is less than 1%, as shown in Figure 4.

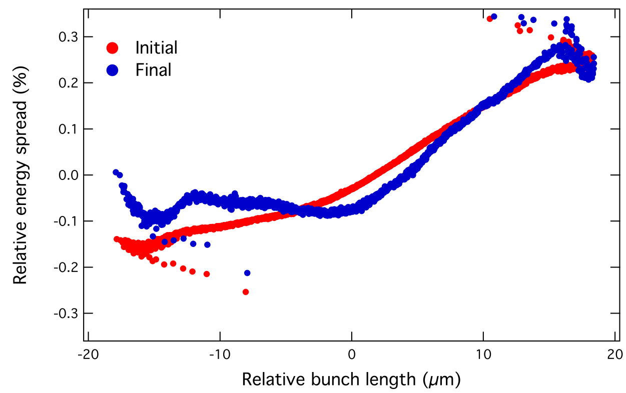

Figure 4: Longitudinal phase space at the beginning and at the end of the switchyard.

In order to evaluate emittances and beam size changes, we have performed simulations with an electron distribution at the entrance of the kicker, which was obtained from a field map output from an ELEGANT simulation for the 200 pC case. For the simulations, the PTC module embedded in the latest MADX [4] version was used. CSR effects are evaluated separately using CSRTRACK [5] (in 1D only) and ELEGANT [6]. The initial beam conditions are shown in Table 1 and have an initial normalized emittance of $\varepsilon_x = 0.47$ mm.mrad and $\varepsilon_y = 0.35$ mm.mrad and an rms bunch length of 8.6 μm. The total effect of CSR on the emittance is negligible, being much smaller than distortions caused by the lattice. For the case with CSR, the amount of projected emittance growth was suppressed by carefully choosing the phase advance between the two bending sets. Although the projected emittance can be very sensitive to the phase advances, the sliced emittance is conserved along the whole switchyard, as shown in Figure 5.

Table 1: Twiss Functions at the End on LINAC2 and at the Entrance of the Switchyard

Twiss Function	LINAC2	Switchyard
β_x	29.6 m	5 m
α_x	-1.93	0.0
β_y	8.6 m	46
α_y	0.55	6

KICKER SEPTUM CONSTRAINTS

Given the requirements of the undulators the maximum orbit jitter acceptable at their entrance is $0.1\sigma_{x,y}$ and, for the Athos beamline, a maximum acceptable emittance growth of 5%. Converting this requirements to shot-to-shot jitter for the kicker and septum setup, and given that the resonant kicker is able to provide a shot-to-shot jitter < 36 ppm or 4×10^{-5} we found that the Septum jitter should be

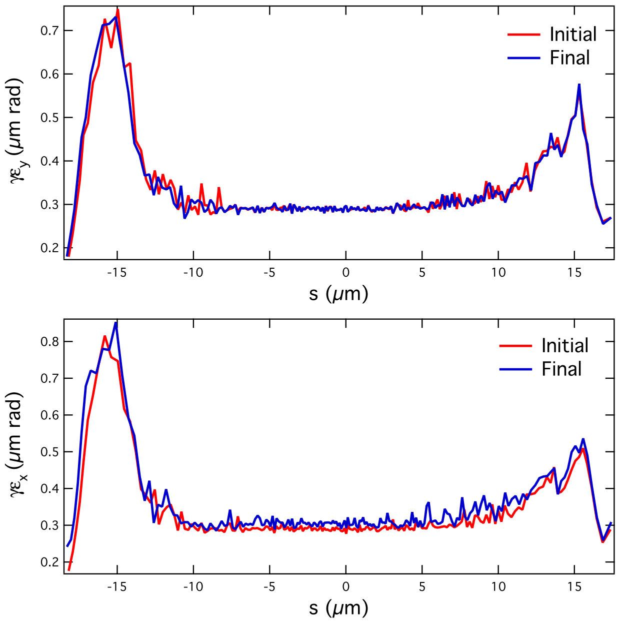

Figure 5: Calculated normalized sliced emittance at the beginning and at the end of the switchyard.

$< 1 \times 10^{-5}$. This requirement is quite challenging making the option for a DC Lambertson magnet more interesting. Further studies on the choice of separation plane and setup for the switchyard are under way.

QUADRUPOLE MISALIGNMENTS

The misalignments of quadrupole magnets have no large impact on the emittance. For a Gaussian distribution of transverse misalignments, with a width of 50 μm, the emittance grows by 6%, and if the spread is reduced to 20 μm, this growth is reduced to 2%. Although the projected emittance does not change much, misalignments can excite betatron oscillations, which can spoil the performance of the undulators. For the misalignment distributions studied, the average rms spread of offsets at the end of the switchyard is 300 μm and 100 μm for misaligments of 50 μm and 20 μm, respectively. These offsets can be corrected by the use of beam-based-alignment and an orbit feedback system [7].

CHARGE FLUCTUATIONS

It was observed in simulations that a total charge error of up to $\pm$ 10% does not cause significant emittance growth or mis-steering, due to changes in the CSR kick strength, of the electron beam and so are not of big concern. Studies on peak charge fluctuation have not yet been addressed.

COLLIMATION AND PROTECTION

The electron bunch deviated towards Athos will first pass through a set of collimators to prevent damaging the undulators. The initial design for the collimator, at the Athos beamline, foresees a set of transverse collimators at the horizontal dispersion free section of the switchyard and a dispersive energy collimator in the second set of DBAs, as shown in Figure 6. For each transverse plane a set of two collimators are separated by a phase advance of 90^o and the apertures are 12 mm and 8 mm for the vertical and horizontal collimators, respectively. Those apertures give an acceptance of $A_x = 1.4$ mm.mrad and $A_y = 1.3$ mm.mrad which is smaller then the limitation of 1.6 mm.mrad at the undulators. For the energy collimation an aperture of 6 mm will give a total momentum acceptance of 1.7 %. Further studies including dark current and halo formation are necessary to optimize the collimators design.

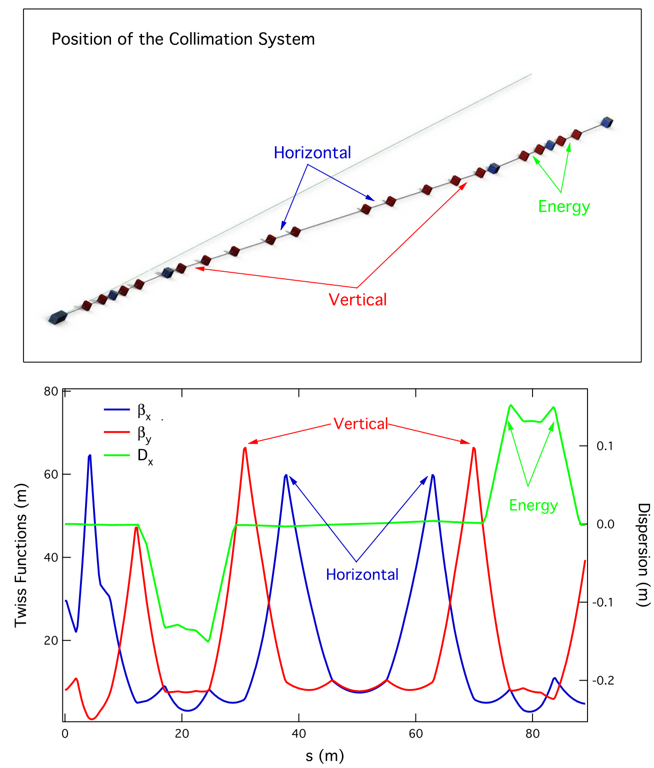

Figure 6: Initial position of the collimation system. Example of the position of the collimation system together with the twiss functions for the case with horizontal deflection (kicker and septum).

CONCLUSION

We have presented two possible schematics for the switchyard, including vertical or horizontal separation. Studies on misalignments, charge fluctuation and on the kicker-septum constraints were also carried out. A preliminary study on the collimation and protection system was initiated and possible locations for the transverse and energy collimators were chosen. Further studies on nonlinearities, chromatic effects and a more detailed study on the collimation setup are under way.

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