SWITCHYARD DESIGN: ATHOS

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Abstract

The SwissFEL facility will produce coherent, ultrabright and ultra-short photon pulses covering a wavelength range from 0.1 nm to 7 nm, requiring an emittance of 0.43 mm mrad or better. In order to provide electrons to the soft X-ray beam line a switchyard is necessary. This beamline will switch the electron bunch coming from the SwissFEL linac, with an energy of 3.0 GeV, and transport it to Athos. The 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 order to keep the switchyard as versatile as possible it can work for a range of values of R_{56} from isochronous up to 6 mm, when the bunch is stretched by a factor two, and also be able to transport the beam in the so called "large bandwidth" [1] mode. In this paper we present the schematics for the switchyard, discuss its many modes of operation, sextupole correction scheme and positioning of energy collimator for machine protection.

SWITCHYARD DESCRIPTION

The switchyard for SwissFEL [2] diverts the beam coming from Linac 2, with an energy of 3.0 GeV, to thesoft X-ray undulator (Athos beamline). At the Switchyard entrance a set of 3 fast resonant kickers [3] followed by a lambertson magnet will deviate the second of the two bunches accelerated in the Linac. This second bunch will then be further transported towards Athos beamline while the first bunch continues straight towards Aramis. In order to allow some flexibility in Athos and to accommodate possible different working configurations, it is possible to setup the switchyard for a range of values of R_{56}.

The switchyard has a total length of 65 m and the separation between the Athos and Aramis beamlines is 3.75 m, with a net bending angle equal to zero, making the two beamlines parallel to each other, as shown in Figure1. This design has one triple-bend (TBA) and one double-bend (DBA) achromat sections; and each section has a total bending angle of 5 degrees. To make the full setup of the switchyard easier, specially during commissioning, it was divided into 4 sections, having each one a specific function:

Section 1 (TBA): The central dipole in the triple bend is weaker and is situated in a high dispersive area, by changing the dispersion function in this magnet we can choose the value of R_{56}, making the sector go from isochronous (no variation on the bunch length) to a value of R_{56} = 6 mm (relative to a bunch lengthening factor of 1.9).

Section 2: Since the kickers deviate the beam vertically it is also required that in the switchyard the beam is brought back to level with respect to the rest of the machine, this is performed by a set of 2 vertical dipoles right after the triple-bend. In this section also, 4 quadrupoles are responsible for closing the vertical dispersion created by the kickers.

Section 3: The phase advance between the two bends (TBA and DBA) is adjustable by changing the settings of the quadrupoles in the transport line (5 quadrupoles after the second vertical dipole). The lattice functions on the dipoles of the switchyard are set to the minimum value possible so that kicks due to coherent synchrotron radiation (CSR) are minimized and by adjusting the phase advance between them, we can compensate for the projected emittance dilution caused by CSR. A de-chirper is also foreseen to be installed in this section.

Section 4 (DBA): Finally, the second bend set is setup in order to accommodate the energy collimators.

KICKER AND SEPTUM

SwissFEL will work in double bunch mode with a bunch time separation of 28 ns and a repetition rate of 100 Hz. In order to separate the beam for the soft x-ray beamline 3 resonant kickers will deflect the beam in the vertical direction and a DC Lambertson magnet will separate it horizontally, 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.

Given the requirements of the undulators the maximum orbit jitter acceptable due to pulsed elements at the switchyard is $0.05\sigma_{x,y}$ and for the Athos beamline, a maximum acceptable projected emittance growth of 5%. In order to estimate the shot-to-shot jitter for the kicker and lambertson we used the following expression

$$\frac{\Delta\theta_{rms}}{\theta} < \frac{0.05}{\theta}\sqrt{\frac{\epsilon_N}{\beta\gamma}} \qquad (1)$$

where $\Delta\theta$ is the angle fluctuation, θ the total bending angle, ϵ_N the normalized emittance, β the beta function at the element position and γ the Lorentz factor. From this expression, and considering the most extreme case of 10 pC operation [2], we find that $\Delta\theta_K < 86$ ppm and $\Delta\theta_L < 3.5$ ppm, for the kickers and lambertson respectively. Those jitter requirements, specially for the kickers, are very tight and are under study.

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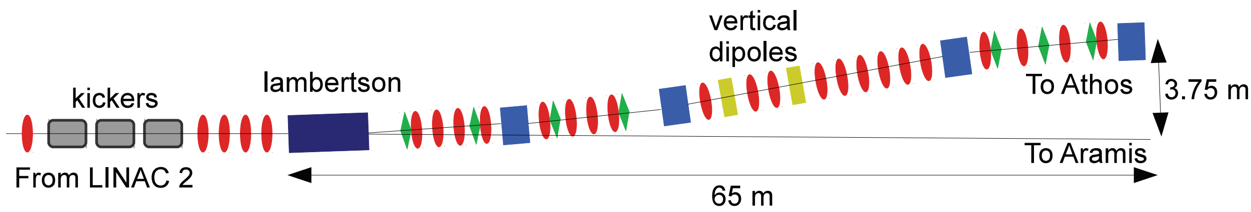

Figure 1: Schematic layout of Athos Switchyard. (blue) horizontal dipoles and lambertson, (yellow) vertical dipoles, (red) quadrupoles, (green) sextupoles.

LATTICE DESIGN AND EMITTANCE CONTROL

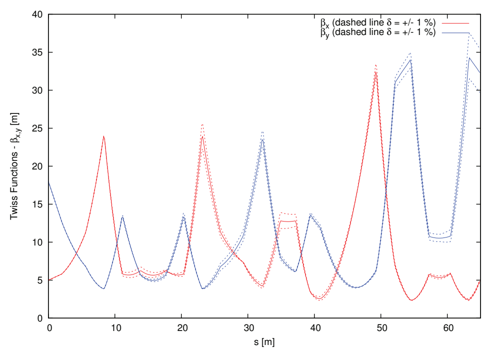

Figure 2: Lattice functions for the case with $R_{56} = 4$ mm. The dashed line are the twiss functions for particles with energy difference of $\delta_E = \pm 1.0\%$.

In order to evaluate emittances and beam size changes throughout the switchyard, we have performed simulations with an electron distribution at the entrance of the lambertson, which was obtained from a particle output from an ELEGANT [4] simulation for the 200 pC case. For the simulations of non-linear effects, the PTC module embedded in the latest MADX [5] version was used. For simulations of misalignments and the energy collimators we used ELEGANT in order to take into account the CSR effects in the dipoles. The initial normalized emittances of the beam are $\epsilon_x = 0.47$ mm.mrad and $\epsilon_y = 0.35$ mm.mrad and a bunch length of 8.6 μm. Figure 2 shows the twiss functions for $R_{56} = 4$ mm and also the residual beta-beat for $\delta_E = \pm 1.0\%$.

The non-linear effects observed in the switchyard are mainly due to chromatic aberrations coming from the quadrupoles and in order to correct it 2 sets of sextupoles where placed in the bending sections. The corrections are localized (closing dispersion and minimizing the beta-beat) at the end of each bending section so as to minimize the sextupole strengths. In Figure 3 we show and example of the effects of the sextupoles for the setup with $R_{56} = 4$ mm. In this case the offsets are almost completely cancelled and there is just a small mismatch at the end of the beamline for particles with an energy offset of 1%. This is not as good for all possible values of R_{56}, and we observed that the residual offset can account for a projected emittance blowup of 1.5% in the nominal operation mode and up to 8% in the large bandwidth mode.

(a) Horizontal (b) Vertical

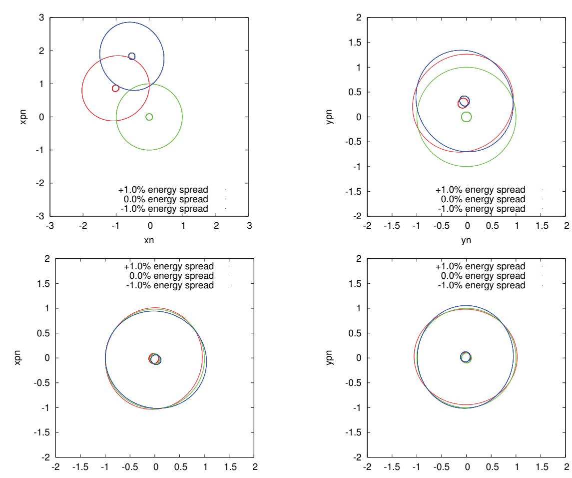

Figure 3: Non linear effects present on the lattice. The plots show the horizontal and vertical phase space for 0.1 and 1σ ellipses and for on energy particles (green dots) and $\delta_E = \pm 1.0\%$ (red and blue dots), (top) sextupoles off and (bottom) sextupoles on.

The total effect of CSR on the emittance is not negligible (Figure 4), however the amount of projected emittance growth can be minimized by changing the phase advance between the two bending sets. Although the projected emittance is very sensitive to the phase advances, the sliced emittance is conserved along the whole switchyard.

MISALIGNMENTS: QUADRUPOLE AND SEXTUPOLE

The misalignments of quadrupole and sextupole magnets have no large impact on the emittance. For a Gaussian distribution of transverse misalignments, centered at zero and with a rms of 50 μm, the maximum projected emittance grow observed in simulations was 3% for the isochronous lattice as shown in Figure 5. 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

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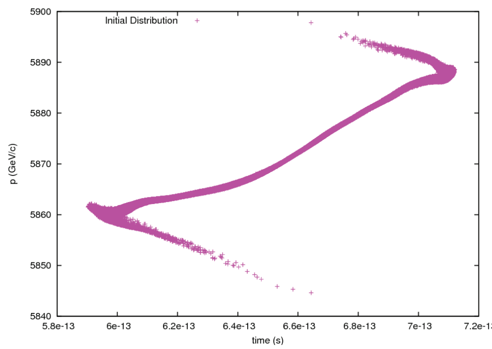
(a) Entrance of the lambertson



(b) End of the switchyard

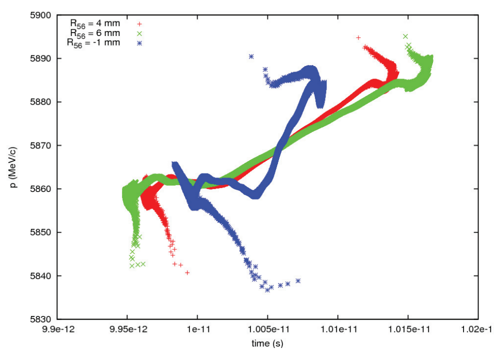


Figure 4: Initial (a) and final longitudinal (b) phase space for different values of R_{56}. The CSR effects are visible in all cases.

average rms spread of offsets at the end of the switchyard is 400 μm and 1000 μm in horizontal and vertical planes respectively. These offsets can be corrected by the use of beam-based-alignment and the orbit feedback system [6].

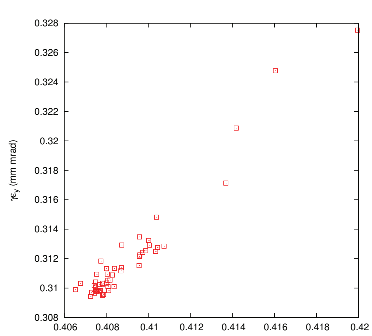


Figure 5: Vertical and horizontal normalized emittance for case with all quadrupoles and sextupoles are random misaligned (Isochronous lattice). For the displacements we used a gaussian distribution with RMS width of 50 μm. This represent the worse lattice in term of sensitivity to magnets alignment.

COLLIMATION AND PROTECTION

The electron bunch deviated towards Athos will first pass through a set of collimators to prevent damaging Athos undulators. The initial design for the collimator, at the Athos beamline, foresees a set of transverse collimators at a FODO type lattice after the switchyard and a dispersive energy collimator with variable gap located in the second set of bends in the switchyard. Two sections of 3 m separated by a phase advance of 90 degrees are reserved for the energy collimators. The maximum dispersion in this section is 0.2 m and in order to have a momentum acceptance of $10\sigma_\delta$ (or $\pm$ 1 %) the collimators gaps should be set to 2.8 mm. The energy collimator should also act as a protection system in case failures in the RF section before the switchyard. Figure 6 shows the loss map for the beam particles when each module of the last accelerating section of the Linac a switched off. Each module adds about 50 MeV to the beam and we only observe partical transmission of particles towards the Athos line when 1 module fails, in this case 80% of the particles are lost in the collimators (Figure 6) and 20% (or 40 pC) are further transmitted. When more than 1 module fails 100% of the particles are lost in the region of the lamberston magnet.

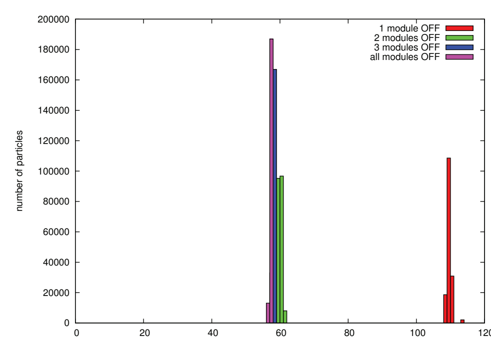


Figure 6: Loss map for the switchyard as we turn off, one by one, the last four modules in Linac 2. In the plot the coordinate system begins at the entrance of Linac 2, the switchyard starts are $s = 55$ m.

CONCLUSION

We have presented the final lattice for the SwissFEL switchyard. In this new setup the switchyard has the flexibility to switch from isochronous to a condition with $R_{56} =$ 6 mm. Studies on the kicker-lambertson constraints, non linear effects, magnets misalignments and energy collimation and protection were also carried out. These studies shows that the effects of the switchyard on beam emittance are minimal even for special modes of operation o f the FEL (i.e. large bandwidth mode). With the lattice and layout frozen, studies to include a de-chirper also in the switchyard sections started and are under way.

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