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DESIGN OF THE BEAM SWITCHYARD OF A SOFT X-RAY FEL USER FACILITY IN SHANGHAI

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Abstract

A soft X-ray FEL user facility, which is based on the existing test facility located in the Zhangjiang Campus of SINAP, is under construction. Two undulator lines will be installed parallelly in the undulator hall. For simultaneous operation of the two undulator lines, a beam distribution system should be used to connect the linac and the undulator lines. In this paper, the physics design of this beam distribution system will be presented and also the beam dynamic issues will be discussed.

INTRODUCTION

The Shanghai Soft X-ray Free-Electron Laser facility (SXFEL) is the first FEL facility targets to touch the soft X-ray range in China [1]. It is located on the campus of the Shanghai Synchrotron Radiation Facility (SSRF), as shown in Figure 1.

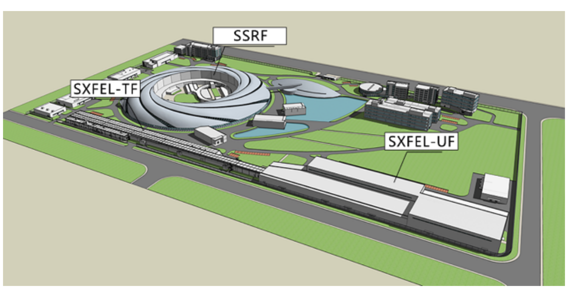

Figure 1: Aerial view of the SSRF and the SXFEL.

The SXFEL was developed in phases, the test facility (SXFEL-TF) which is under commissioning and the user facility (SXFEL-UF) which will be installed later. The SXFEL-TF is designed for testing advanced FEL concepts such as high-gain harmonic generation (HGHG) and a combination of echo-enabled harmonic generation (EEHG) and HGHG. The beam energy is about 840 MeV and the radiation wavelength is 8.8 nm. Based on the SXFEL-TF, SXFEL-UF will upgrade the beam energy to 1.5 GeV in order to extend the radiation wavelength to cover the water window region. SXFEL-UF will have two individual undulator lines, a SASE-FEL line with radiation wavelength about 2 nm and a seeding-FEL line with the radiation wavelength about 3 nm. The two undulator lines will be installed parallelly in the undulator hall. For simultaneous operation of the two undulator lines, a beam distribution system should be used to connect the linac and undulator lines. In this paper, the physics design of such a beam distribution system will be described and some related beam dynamic issues will be discussed. For the schematic layouts see Fig. 2.

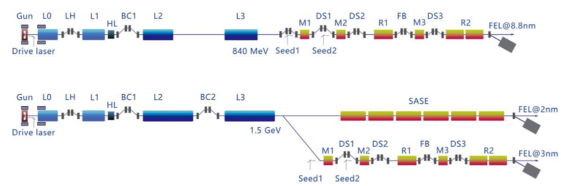

Figure 2: Schematic layouts: SXFEL-TF (upper) and SXFEL-UF (lower).

GENERAL DESCRIPTION OF THE SWITCHYARD

Linac Parameters

SXFEL-TF has a normal-conducting linac consists of a set of S-band and C-band accelerator structures. For the SXFEL-UF, more C-band structures will be installed down stream of the original linac for increasing the beam energy from 840 MeV to 1.5 GeV. A comparison of some main parameters of the linac between SXFEL-TF and SXFEL-UF is shown in Table. 1

Table 1: Main Parameters of the SXFEL Linac

Parameters	Units	SXFEL-TF	SXFEL-UF
E	GeV	0.84	1.5~1.6
σ_E/E (rms)		≤0.1 %	≤0.1 %
ε_n (rms)	mm·mrad	≤2.0	≤1.5
l_b (FWHM)	ps	≤1.0	≤0.7
Q	pC	500	500
I_{pk}	A	≥500	≥700
f_{rep}	Hz	10	50

General Layout

After the linac there are two undulator lines installed in the undulator hall. The one which goes straight from the linac is the SASE-FEL line and the seeding-FEL line lies 3 m right side of the SASE-FEL line. The 1.5 GeV electron bunch train with 50 Hz repetition rate are separated bunch-by-bunch by a fast kicker and then propagated to the two undulator lines respectively. For the deflecting line, i.e., the way goes to the seeding-FEL line, the general layout should be a dog-leg structure, as is shown in Figure 3.

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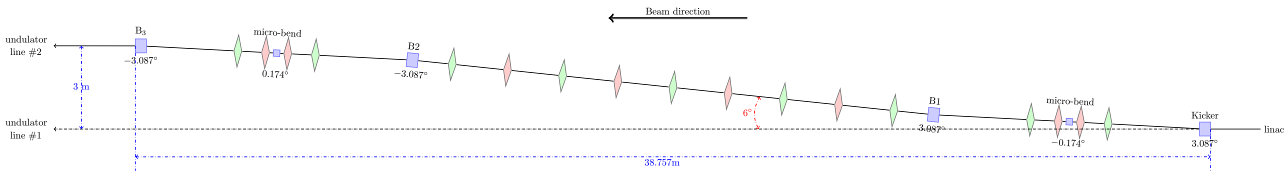

Figure 3: Schematic layouts of the beam switchyard of SXFEL-UF. Beam comes from the right side.

The dog-leg consists of the fast kicker magnet and three successive DC dipoles. The kicker magnet and the first DC dipole has the same bending angle. Several quadruples are installed between them for eliminate the dispersion, i.e., they constitute a double-bend-achromat (DBA). The total bending angle of this entrance DBA is 6°. The other two DC dipoles constitute another DBA (−6°) at the exit of dog-leg. The two DBAs are centrosymmetric with the dog-leg. Between two DBAs, there are several quadruples for beam matching. The position of elements has been adjusted carefully in order to avoid conflict between the straight line and the deflecting line. The total projected length of the dog-leg is about 38.76 m.

OPTICS DESIGN AND EMITTANCE CONTROL

The optics of the beam switchyard line should affect as less as possible to the beam quality from linac. For this purpose, the dog-leg should be achromatic and isochronous. Figure 4 shows the β functions and the horizontal dispersion function along the dog-leg.

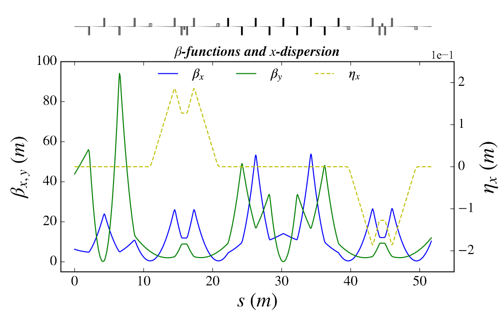

Figure 4: β functions and horizontal dispersion function from the end of linac to the end of dog-leg.

With the due-DBA scheme, the dog-leg is achromatic locally and globally on first and second order. For suppressing the coherent synchrotron radiation (CSR) induced emittance growth, the optics from the entrance of kicker magnet to the exit of the last dipole is matched to be symmetrical and the β functions at the dipoles are optimized to be very small to reduce the strength of CSR kick. Besides, the phase advance between each two successive dipole is match to be π in order to cancel the CSR kick [2,3]. Figure 5 shows the normalized emittance evolution along the beam switchyard. It is seen that with such an optics design, the emittance growth after the dog-leg is less than 1 % compared with the emittance at the end of linac.

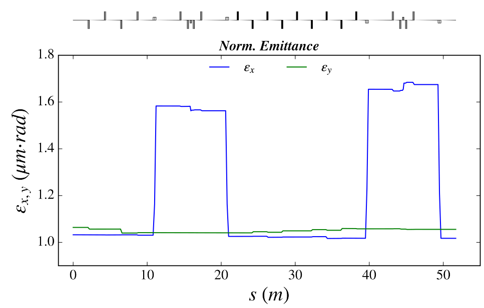

Figure 5: Normalized emittance along the beam switchyard.

SUPPRESSION OF MBI

Microbunching instability (MBI) is another key beam dynamic issue of the switchyard. The MBI generated in the linac can have large gain in the switchyard line with no-zero R_{56} transport matrix element. It is very harmful for producing intense coherent radiation with very narrow spectral bandwidth. In SXFEL-UF, MBI appears in the longitudinal phase space at the end of linac due to two stage compressions and even the laser heater is insufficient for suppressing it, as is shown in Figure 6. MBI gain suppression has to be considered in the switchyard design.

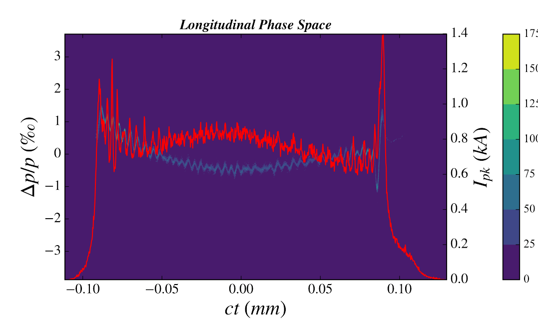

Figure 6: Longitudinal phase space and current profile at the end of linac.

In the switchyard of SXFEL-UF, the global R_{56} generated by the kicker and dipoles is about 750 µm. For MBI suppression, it is better to slash the R_{56} to be almost zero, i.e., make

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the lattice isochronous. It is realized by adding a "micro-bend" in the mid-point of each DBA [4]. The micro-bend has a small but inverse deflection angle compared with the original dipoles of DBA. Meanwhile, the bending angles of the entrance and exit dipoles are adjusted symmetrically to keep the overall angle of DBA. As is shown in Figure 7.

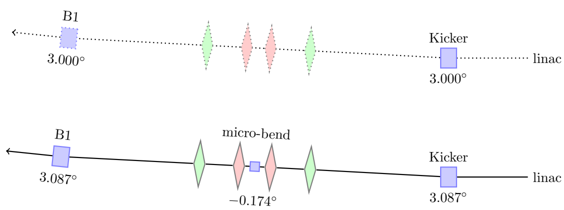
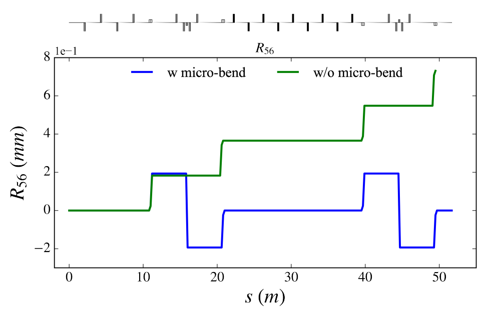
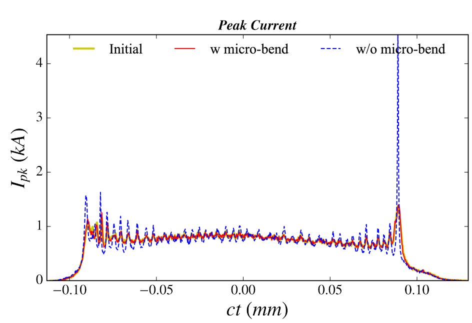


Figure 7: Insert micro-bend in the middle of DBA.

Figure 8(a) shows the comparison of R_{56} with/without micro-bend. The R_{56} reduces from about 750 µm to less than 1 µm by introducing the micro-bend. Figure 8(b) shows the comparison of the bunch current profile with and without micro-bend. It is seen that the MBI grows significantly without micro-bend, especially at the head and tail of the bunch. In contrast, the MBI gain is well suppressed in the case with the micro-bend. The change of current profile compared with the initial current profile is barely distinguishable.



(a) Evolution of R_{56} along the switchyard



(b) Comparison of the current profile

Figure 8: Comparison between the case with/without micro-bend.

JITTER ANALYSIS

Figure 9 shows the transverse position jitter at the exit of switchyard. The jitter is mainly caused by the magnet power supply jitter, which is typically random. With the kicker jitter (RMS) ∼100 ppm, dipole jitter ∼ 50 ppm and quadrupole jitter $\sim 1 \times 10^{-3}$. The horizontal position jitter (RMS) at the exit of switchyard is less than 10 % but very close and the vertical position jitter (RMS) is less than 5 %. The seeding-FEL requires a transverse position jitter less than 10 % so that this could be a criterion for the hardwares [5].

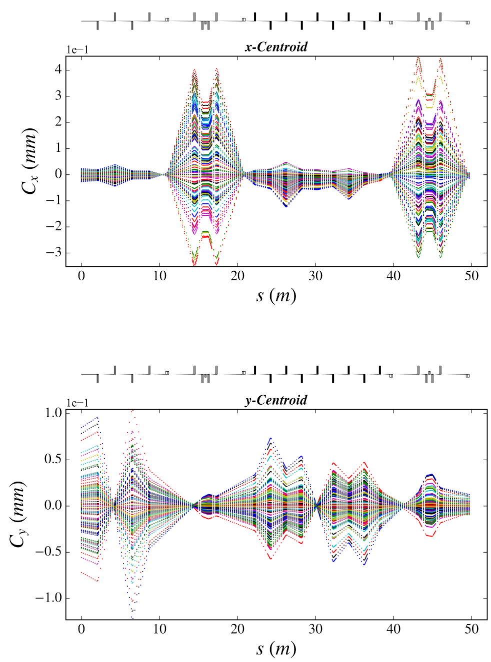


Figure 9: Transeverse position jitter of 50 cases of magnet power supply jitter.

SUMMARY

The beam switchyard of SXFEL-UF is designed to be able to realize bunch-by-bunch distribution between the two undulator lines. With properly optimization, it has an achromatic and isochronous lattice with well preserved beam quality. In the next stage, this beam switchyard will be installed and have commissioning on SXFEL-UF in 2019.

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