LONGITUDIANL WAKEFIELDS IN THE UNDULATOR SECTION OF SXFEL USER FACILITY*

M. Song, D. Huang, C. Feng, H. Deng, B. Liu, D. Wang, SINAP, Shanghai, 201800, China

Abstract

Shanghai soft x-ray free electron laser (SXFEL) user facility based on multi-stage seeded-FEL and self-amplified spontaneous emission (SASE) is recently proposed, which is aiming at generating 4-2 nm fully-coherent, high-brightness FEL pulse. In this paper, the wakefields arise from the resistive wall and surface roughness in the vacuum chamber is obtained by theoretical models. And the computations of geometric wakefields are carried out using ABCI. According to the tracked beam profile, the overall wakefields in the undulator section of SXFEL user facility are presented.

INTRODUCTION

Free electron laser (FEL) holds the promise to generate a short pulse, high intensity radiation source in the frequency range from Terahertz to hard X-ray. Due to its ultra-high brilliance and full coherence properties, the widespread scientific applications will be considered, such as molecular biology, material science, catalysis engineering and medical science. Currently, more and more X-ray FEL user facilities are under operation or construction around the world and preparing to satisfy the requirements of the scientists. Currently, the first X-ray FEL in China is under construction at Shanghai, namely SXFEL. As a test facility, the baseline design of SXFEL is a 9 nm two-stage seeded FEL with 0.84 GeV electron beam [1]. And converting SXFEL from test facility to user facility is a topic ever of great interest. More recently, SXFEL user facility is under consideration seriously.

The basic idea of SXFEL user facility is illustrated in Fig. 1. On the basis of SXFEL test facility, the reserved space in LINAC will be filled by 4 additional C-band accelerating modules, which further boost the electron beam energy from 0.84 to 1.5 GeV. Under such beam energy, the original undulator line under construction based on the frequency up-conversion scheme of the initial coherent 265 nm seed pulse in an FEL amplifier reaches 3.0 nm wavelength. In order to guarantee FEL saturation at 3.0 nm, 7 additional undulator segments will be added to the undulator line employing multi-stage HGHG [2], EEHG [3] and/or PEHG [4]. Meanwhile, a totally new undulator branch line will be constructed as high flux FEL mode, which will cover the entire water-window wavelength (typically 2.0 nm). To satisfy the requirements of short wavelength and lasing efficiency, a SASE [5] type which simply made up of in-vacuum undulator and insertion device rise up. For example, the magnetic length of the individual undulator is 5.0 m (undulator period is 15 mm) and 1 m for the each connection segment, respectively.

In addition to the two undulator line shown above, the main parameters are summarized in Table 1. It should be pointed out that the parameters are tentative and still need to be optimized.

The longitudinal wakefields of SXFEL test facility and its effects on FEL radiation pulses has been studied intensively [6], under Gaussian assumption of beam temporal profile. In this paper, the wakefields calculations from the resistive wall, surface roughness, and the discontinuities of beam-pipe are presented for SXFEL user facility, and the real beam profile from LINAC tracking is used.

Table 1: Main Parameters of SXFEL Test Facility and User Facility

	Units	Test facility	User facility	
			Seeded	SASE
Beam energy	GeV	0.84	1.5	1.5
Peak current	A	500	> 700	> 700
Bunch charge	pC	500	500	500
Emittance	μm-rad	2	1.5	1.5
Undulator length	m	3m×9	3m×14	5m×8
β function	m	8-10	8-10	8-10
Vacuum chamber	mm	6×15	6×15	3-5
Wavelength	nm	8.8	3.0	2.0

WAKE POTENTIAL CALCULATIONS

It is deserved noting that linear accelerator is made up of relative simple and large aperture structures while compared with complex undulator section in SXFEL user facility. Meanwhile, the energy loss caused by wakefields is small as the interaction between low peak current electron beam and impedance items in linear section. Furthermore, the energy loss can be monitored and compensated with the help of RF cavity. Accordingly, we limit our consideration to calculate the wakefields of undulator section.

Resistive Wall and Surface Roughness

What are generally considered in undulator vacuum chambers are resistive wall and surface roughness wakefields. For SXFEL user facility of cascade HGHG type, a 3.34 m long aluminium vacuum chamber will be adopted together with the stage-1 and stage-2 radiators consist of 4 and 10 undulator segments. The cross section of undulator beam pipe has an elliptical shape, which the full aperture is 6 mm by 15 mm, vertical by horizontal. In terms of wake effects can be well approximated by cylindrical pipe which designated as round geometry.

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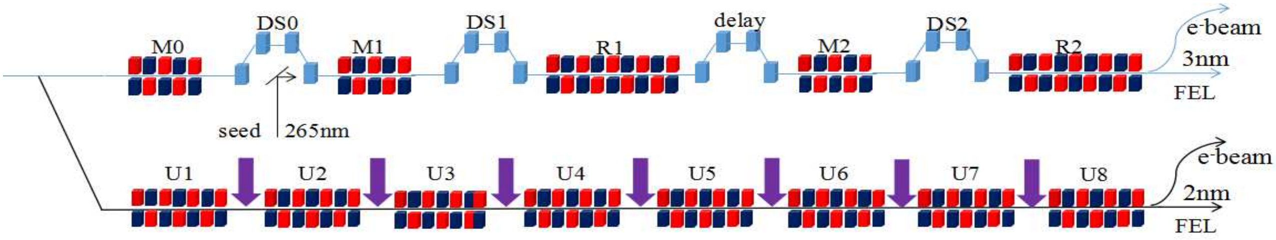

Figure 1: Layout of the SXFEL user facility which has two branches represented for HGHG and SASE FEL type.

However, unlike the cross section of the former type, a parallel flat chamber will be considered in SASE FEL type due to the application of in-vacuum undulators. What's more, the computation of the short range resistive wall and roughness wakefields can be accomplished theoretically. At the exit of linear section and before the entrance of undulator section, a bunch length of 0.8 ps with a peak current of 800 A or 1000 A accompanied by bunch length of 0.6 ps can be delivered with a 500 pC bunch charge.

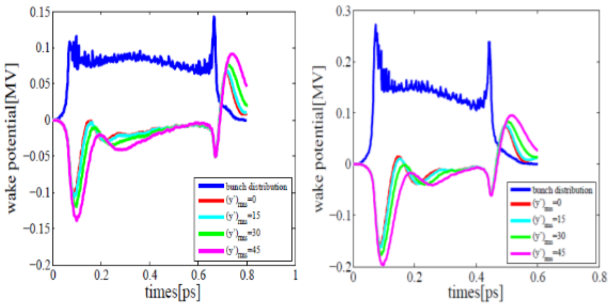

Figure 2: The left shows the HGHG type total wake potential of a 3.34 m long vacuum chamber for the AC resistance model of aluminum plus the effects of the roughness model of peak current 800 A, for the case $(y')_{rms}$=0,15,30,45 mr. The right shows the case for peak current of 1000 A. Here the wall oscillation wavelength is 300 µm.

The SXFEL user facility bunch distribution in the undulator is not exactly Gaussian profile with peak current 800 A or 1000 A, the current obtained 500 pC distribution has horns at the head and tail of bunch, with a current drop in the middle part.

Figure 2 presents the wake potentials of one undulator for the peak current of 800 A and 1000 A. On the basis of the results together with real bunch profile shown in the plot, the mean energy loss of the total wakefields are approximately 26.5 keV and 40.3 keV for the peak current of 800 A and 1000 A provided that $(y')_{rms}$=30 mr, respectively. Meanwhile, for the another FEL type wake potentials of undultor shown in Fig.3, the average energy deviations of the total wakefields are nearly 115 keV, 56 keV and 44 keV for the peak current of 800 A corresponding to gap from 3 mm to 5 mm under the circumstance of $(y')_{rms}$=30 mr, separately. Also for the peak current of 1000 A, the mean energy losses are approximately 119 keV, 85 keV and 66 keV under the same conditions.

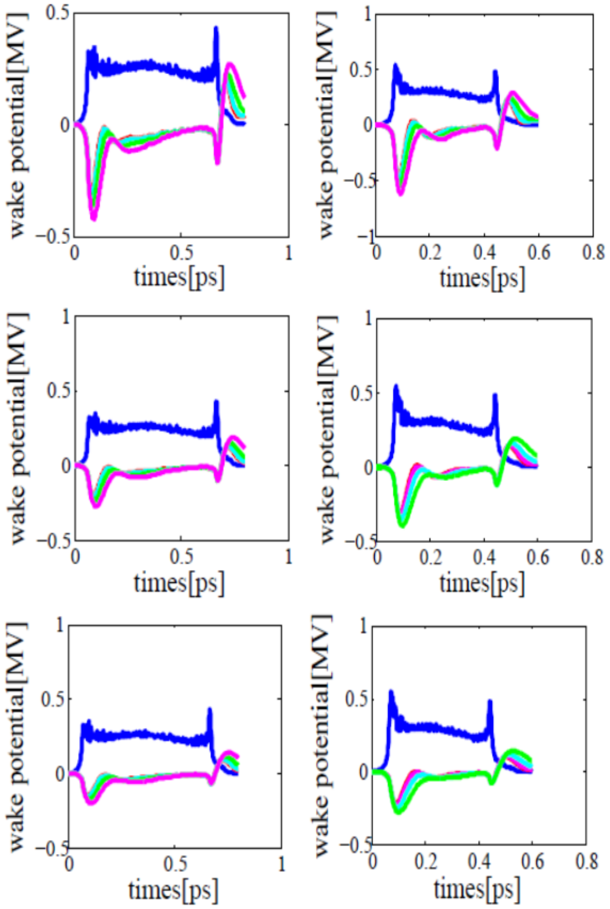

Figure 3: The left column shows the SASE FEL type total wake potential of a 5 m long vacuum chamber together with the gap range from 3 mm,4 mm to 5 mm that under different RMS slope of surface for peak current of 800 A. The right shows the case for peak current of 1000 A. The oscillation wavelength presumed the value of 300 µm. For the case $(y')_{rms}$=0,15,30,45 mr are represented by red, cyan, green and pink lines.

Geometrics

It is found that the composition of the undulator section is quite complicated due to the connection of considerable number of required impedance items. Besides the common geometrics like flanges, bellows, a quantity of placement of profile monitor together with quadrupoles, correctors and phase-shifters can be found as well.

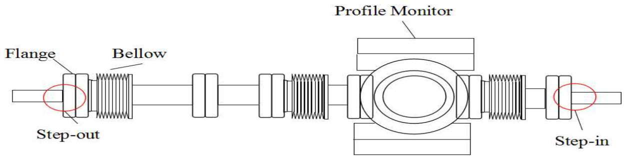

Figure 4: One module of the insert components between two adjacent undulator segments

Using the ABCI [7] codes, the short range wakefields of segment between two undulators shown in Fig. 4 will be investigated for both HGHG and SASE FEL type, although some shielding efforts have been devoted to diminish the wake effects of bellows. The Fig. 5 presents the wake potentials evolution of different peak current. On the basis of plots, it can be obtained that mean beam energy loss is nearly 63 keV for the peak current of 800 A. However, for the peak current of 1000 A, the average energy deviation is approximately 77 keV.

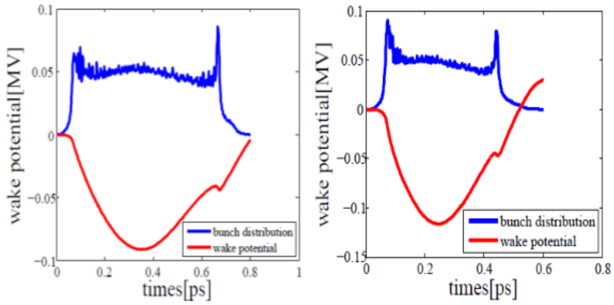

Figure 5: The left shows the wake potential of the inserting module, using bellows with (red) shielding for the peak current of 800 A, the right shows the case for the peak current of 1000 A.

Total Wakefields Induced Beam Energy Loss

Here the whole undulator section is divided into several modules to compute and obtain total energy loss when the electron beam running through the undulator section. Generally, detailed studies of resistive and roughness induced wakefields will be carried out with the help of theoretical analysis plus the geometrics placed between or beyond undulators simulated by ABCI [7] program codes. Figure 6 illustrates the process of wake potentials of electron beam located at the exit of two stages for the peak current of 800 A and 1000 A of cascade HGHG scheme. Obviously, the wake effects become more and more severe from the evolution of the plots. Accordingly, the total energy loss is approximately 1.4 MeV at the end of undulator section, which is smaller compared to the condition of peak current of 1000 A together with the whole energy deviation is nearly 1.8 MeV. For the SASE type, the total energy losses for the peak current 800 A are nearly 1.13 MeV, 0.95 MeV, 0.85 MeV corresponding to the gap ranging from 3mm to 5mm, respectively. For the peak current of 1000A, the whole energy deviations are approximately 1.57 MeV, 1.29 MeV, 1.14 MeV under the same circumstances, separately.

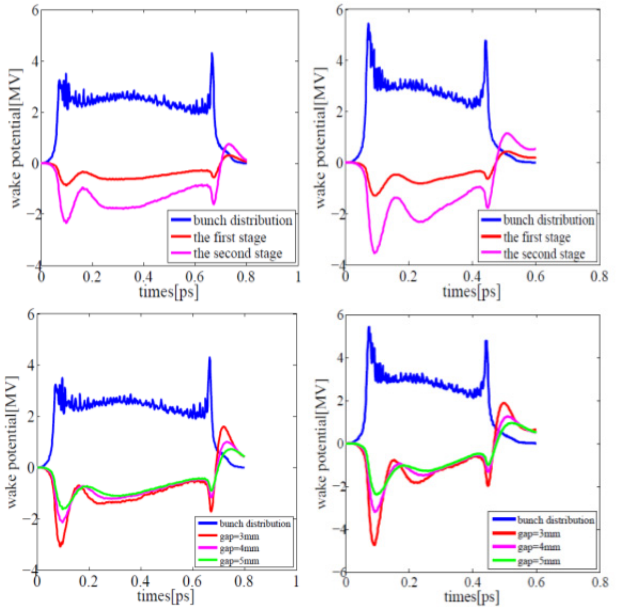

Figure 6: The upper plots show the seeded FEL wake potentials of the electron beam experienced at the exit of two stages for the peak current of 800 A, and the case for the peak current of 1000 A. The lower plots present the SASE type wake potentials evolution with the gaps ranging from 3 mm to 5 mm for the peak current of 800 A and 1000 A. Here the bellows are shielded together with $(y')_{rms}$=30 mr.

CONCLUSION&OUTLOOK

Generally speaking, the structure of linear section is relative simple compared to the sophisticated undulator section. Meanwhile, the feedback system exists in the LINAC rather than undulator section. Therefore, in this paper, the longitudinal wakefields in the undulator section generated by resistive wall, surface roughness and geometrics will be computed in regard to the different peak current and FEL type. It can be demonstrated that the whole energy deviation in the undulator section for the peak current of 800 A is smaller compared to another case towards higher peak current. However, it is worth to stress that wakefields calculation is the initial work for SXFEL user facility. Therefore a more accurate 3-D wake model simulation is under development with CST software. And the FEL performance simulation will also be carried out in the future.

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