

PARALLEL OPERATION OF SASE1 AND SASE3 UNDULATOR SECTIONS OF EUROPEAN XFEL

A. A. Sargsyan*, V. V. Sahakyan, CANDLE Synchrotron Research Institute, Yerevan, Armenia
W. Decking, DESY, Hamburg, Germany

Abstract

In the current paper the numerical simulation results for parallel (decoupled) operation of SASE1 and SASE3 undulator sections of European XFEL are presented. The study was based on the idea of betatron switcher implementation. It was shown that it is possible to avoid energy spread growth in SASE1 and to reach the saturation in SASE3 in desirable range of radiation wavelengths by a trajectory kick before SASE1 and its correction before SASE3.

INTRODUCTION

According to the current design of European XFEL three undulator lines will be installed at the first stage: SASE1, SASE2 and SASE3. SASE3 undulator line is placed after SASE1 in the same electron beamline. All undulators are 5 m long and the spacing between the modules is 1.1 m. Undulators of SASE1 and SASE2 are identical. Each line consists of 35 modules, each having 40 mm period length and a gap varying in the range of 10-20 mm. SASE3 undulator line (with total length of 128.1 m) consists of 21 modules with a period length of 68 mm and a gap tunability range of 10-25 mm. The schematic layout of European XFEL undulator sections is presented in Fig. 1.

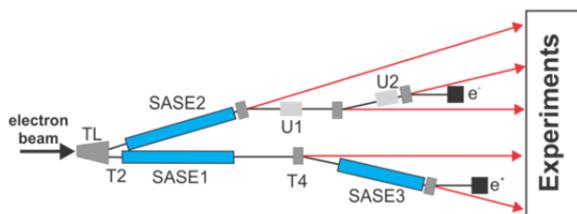


Figure 1: The schematic layout of European XFEL undulator sections.

For European XFEL operation four different energy modes are foreseen: 17.5 GeV, 14 GeV, 12 GeV and 8.5 GeV. The operating range for bunch charge is from 20 pC to 1 nC, the peak current is 5 kA, and the normalized rms emittance is between 0.3 and 1 mm-mrad, depending on bunch charge. The tunability range of undulator parameter is 1.65 - 3.9 and 4 - 9 for SASE1/2 and SASE3, respectively. Thus, SASE1 and SASE2 will cover the range of radiation wavelengths from 0.04 to 0.62 nm, and SASE3 - from 0.27 to 5.17 nm.

The usage of the electron beam, coming from SASE1, puts limitations on SASE3 operation. The general problem is that the lasing process in SASE1 causes high-induced energy spread in the electron beam which leads

* asargsyan@asls.candle.am

to degradation of SASE3 performance. Thus, the operation of SASE3 as an afterburner of SASE1 is possible with a reduced range of accessible wavelengths and radiation energy.

Decoupling of SASE1 and SASE3 operation can be performed by the application of betatron switcher proposed by R. Brinkmann, E. Schneidmiller and M. Yurkov [1-2]. The idea is to use a fast kicker in front of SASE1 undulator line and give angular kicks to a part of bunches. Trajectories of kicked bunches strongly deviate from the straight path and as a result these bunches do not lase in SASE1, thus, avoiding the increase of energy spread. The kick is compensated before SASE3 by using two corrector magnets, after this bunches go straight and lase to saturation in SASE3.

In this paper the results of numerical study for SASE1 and SASE3 parallel operation, based on betatron switcher implementation, are presented.

NUMERICAL SIMULATIONS

In the numerical study ASTRA [3] output beam files before TL section (Fig. 1) were used. First of all, they were converted to ELEGANT [4] input files. Then particles were tracked through TL and T2 sections, where they are kicked by one of two available fast kickers (K1 or K2). Before entering the first undulator of SASE1 the files of the kicked beams were converted from ELEGANT output into GENESIS [5] input. Further, after GENESIS time-dependent FEL simulations for SASE1, they were converted back into ELEGANT files and tracked through T4 section, where the corrections of trajectories were made. Before entering the first undulator of SASE3, the beam files once again were converted into GENESIS input files and then were used for FEL simulations in SASE3.

In the study electron beams with 1 nC bunch charge were used. In Table 1 the considered values of beam energy and radiation wavelengths are given.

Table 1: Beam Energy and Radiation Wavelength

| Beam energy (GeV) | λ_{SA1} (nm) | λ_{SA3} (nm) |
|-------------------|----------------------|----------------------|
| 17.5 | 0.1 | 0.4 |
| 14 | 0.23 | 0.4 |
| 8.5 | 0.62 | 1.1 |

In simulations the boundary values of wavelengths were considered according to undulator K parameter's possible values in SASE1 and SASE3, since on the one hand, in longer wavelengths the lasing goes faster and it is

harder to disturb it by an induced betatron motion in SASE1, and on the other hand in shorter wavelengths it becomes harder to reach saturation in SASE3. In other words, the most difficult cases for realizing SASE1 and SASE3 decoupled operation were considered.

Conversion Scripts

During simulations beam files were converted several times between simulation programs. For these conversions SDDS toolkit was used and several MATLAB scripts were developed. For the conversion from GENESIS output into ELEGANT input the written MATLAB script takes into account different treatments of macro-particles in these programs. In GENESIS output file the beam is presented in the form of slices, and all slices have the same number of macro-particles, but different currents, which is not the case for ELEGANT file, where all macro particles are identical. Taking all macro-particles from GENESIS output would lead to the loss of beam current profile, and it would become impossible to perform correct FEL simulations for SASE3. For solving this disagreement and retaining the current profile after conversion, the written script takes not all macro-particles from i-th slice, but randomly chooses (since distributions of particle transverse coordinates within slices are uniform) an amount according to

$$N_i^T = N_i \cdot \frac{I_i}{I_{\max}}$$

where N_i is the number of macro particles in i-th slice, I_i is the current of i-th slice and I_{\max} is the maximum slice current.

SIMULATION RESULTS

In this section the results of numerical simulations for 17.5 GeV, 14 GeV and 8.5 GeV operating energy cases are presented.

For 17.5 GeV beam energy case the kick value equal to 2, 4 and 6 μ rad at K1 fast kicker and 6 μ rad at K2 were considered. In Fig. 2 GENESIS time dependent simulation results for SASE1 are presented. It can be seen that for 2 μ rad kick value at K1 the radiation energy is reduced but the saturation remains. For 4 and 6 μ rad kick values the radiation energy becomes significantly lower and the lasing process in SASE1 is destroyed. In these considered cases the maximum deviation of beam centroid is less than 280 μ m. Note that if 6 μ rad kick is given at K2 fast kicker, the destructive effect on lasing process in SASE1 is as strong as when the same kick is given at K1, but the maximum deviation of beam centroid is 21% less, which makes the second kicker more preferable in point of view of resistive wall wakefields.

In Fig. 3 the beam energy spread profile after SASE1 is shown where one can see that when the kick value increases, the energy spread becomes lower. In particular, when the kick value is 6 μ rad at K1 it has almost the same profile as for input beam, which points out a complete destruction of lasing in SASE1.

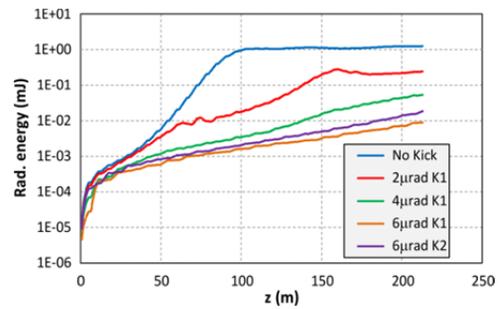


Figure 2: Radiation energy along SASE1.

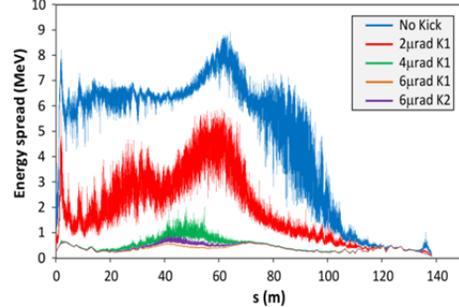


Figure 3: Beam energy spread profiles after SASE1.

In Figure 4 the radiation energy along SASE3 is presented. From the plot it can be seen that in case of undisturbed bunches the energy spread growth in SASE1 led to a significant reduction of radiation energy in SASE3. On the other hand, the realization of the described scheme for 4 and 6 μ rad kicks at K1 and for 6 μ rad kick at K2 resulted in the growth of radiation energy almost in the same way as if SASE1 would be off for an undisturbed beam.

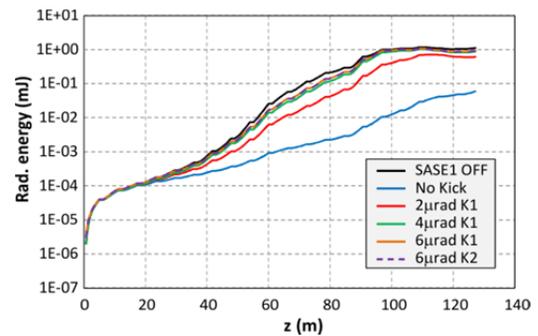


Figure 4: Radiation energy along SASE3.

For 14 GeV beam energy case 4, 6 and 8 μ rad kick values at K1 fast kicker and 8 μ rad at K2 were considered. Here, except for 4 μ rad kick case at K1, the radiation energy becomes significantly lower and the lasing process in SASE1 is destroyed. In the considered cases the maximum deviation of beam centroid was less than 360 μ m. As simulations showed the growth of radiation energy along SASE3 in case of 8 μ rad kick value at K1 is almost the same way as for SASE1 off case.

In 8.5 GeV beam energy case, when the radiation wavelength in SASE1 is longer, as it was expected, it was harder to destroy the lasing process by inducing betatron oscillations. For this energy case 8 μ rad kick value at K1 and K2 were considered. In both cases the saturation is maintained and the energy at saturation is not significantly changed (see Fig. 5). Bigger kick values were not con-

Table 2: Trajectory maximum deviation in SASE1 and relative change of saturation length and radiation energy at saturation for the considered preferable kick values.

| Beam energy (GeV) | λ_{SA1} (nm) | λ_{SA3} (nm) | Pref. kick value | Traj. max. dev. in SASE1 (μm) | SASE3 | |
|--|----------------------|----------------------|-------------------------|--|-------------------------------------|-------------------------------------|
| | | | | | $L_{sat}/L_{sat}^{(SA1\text{off})}$ | $E_{sat}/E_{sat}^{(SA1\text{off})}$ |
| 17.5 | 0.1 | 0.4 | 4 μrad at K1 | 173 | 1.04 | 0.91 |
| 14 | 0.23 | 0.4 | 8 μrad at K1 | 352 | 1.02 | 0.78 |
| 8.5 ($\beta_{av} = 33\text{m}$) short SASE1 | 0.62 | 1.1 | 8 μrad at K2 | 300 | 1.01 | 0.98 |
| 8.5 ($\beta_{av} = 17\text{m}$) | | | 8 μrad at K2 | 227 | 1.78 | 0.45 |

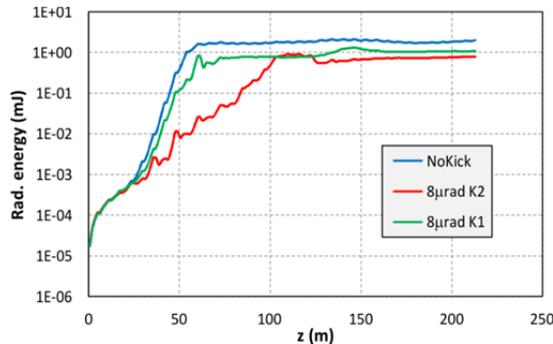


Figure 5: Radiation energy along SASE1.

considered because of undesirable beam centroid large deviations they would cause. Hence, in this case reasonable kick values are not able to make the scheme work. Two solutions were considered: 1) turn off the part of undulators which are located after the saturation point of undisturbed beam, 2) increase the number of betatron oscillations by decreasing the average beta function in SASE1. In case of the first approach it turned out that 8 μrad kick by the second fast kicker is enough to get satisfactory result in SASE3. As a second solution the average value of beta function in SASE1 was changed from 33 m to 17 m, which doubled betatron oscillations that the beam centroid performs. As compared to 33 m average beta case, here, in the same range of kick values, the radiation energy in SASE3 is higher. However, these results are worse compared with the results given by the first solution.

Simulation results for the considered preferable kick values are summarized in Table 2, where trajectory maximum deviations in SASE1 and relative changes of saturation length and radiation energy at saturation point in SASE3 are given.

SUMMARY

In the current paper the parallel (decoupled) operation of SASE1 and SASE3 undulator sections of European XFEL has been studied. It was shown, that by inducing betatron oscillations in SASE1 undulator line, by using fast kickers of section TL and correcting beam trajectory before SASE3 with two corrector magnets of section T4, it is possible to avoid energy spread growth in SASE1 and to reach saturation in SASE3 in the desirable range of

radiation wavelengths. The cases of 17.5, 14 and 8.5 GeV beam energy were considered.

For 17.5 GeV beam energy case the radiation wavelength was assumed to be 0.1 nm in SASE1 and 0.4 nm in SASE3. Different kick values at the positions of two fast kickers, located in section TL, were examined. Numerical simulation results showed that kick values bigger than 4 μrad are enough to destroy the lasing process in SASE1 and provide saturation in SASE3.

The same investigation was done for 14 GeV energy case, considering the longest possible radiation wavelength in SASE1 (0.23 nm) and the shortest wavelength in SASE3 (0.4 nm). Here it was shown that 8 μrad kick by the first fast kicker brings almost to the same result for radiation energy in SASE3 as in the case when SASE1 is off for an undisturbed beam.

In 8.5 GeV energy case 0.62 nm and 1.1 nm boundary values of radiation wavelengths in SASE1 and SASE3, respectively, were considered. The results showed that in this case reasonable kick values are not able to make the scheme work, necessitating the implementation of additional solutions such as shortening SASE1 undulator line or lowering the average beta function.

ACKNOWLEDGMENT

Authors would like to express their gratitude to Dr. G. Feng for helpful discussions and provided ASTRA beam files.

REFERENCES

- [1] R. Brinkmann, E. A. Schneidmiller, M. V. Yurkov, "Possible operation of the European XFEL with ultra-low emittance beams", Nucl. Instr. Meth. In Phys. Res. A, vol. 616, pp. 81-87, 2010.
- [2] E. A. Schneidmiller, M. V. Yurkov, "An Overview of the Radiation Properties of the European XFEL", in *Proc. of FEL'14*, Basel, Switzerland, Aug. 2014, MOP066, pp. 204-209.
- [3] K. Floettmann, ASTRA, <http://www.desy.de/~mpyflo/>.
- [4] M. Borland, "elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation", Advanced Photon Source LS-287, 2000.
- [5] S. Reiche, "GENESIS 1.3: a fully 3D time-dependent FEL simulation code", Nucl. Instr. Meth. In Phys. Res. A, vol. 429, pp. 243-248, 1999.